AD-A240 629

USACERL Technical Report M-91/18
July 1991

2

US Army Corps
of Engineers
Construction Engineering
Research Laboratory

Guide for Visual Inspection of Structural Concrete Building Components

by
Douglas E Ellsworth
Keith Ginnado

Proper inspection of building components can help reduce the likelihood of structural failures. Although inspectors at Army installations are responsible for monitoring the conditions of structural concrete, they currently have no organized method of inspecting this building component.

This report provides Army installation inspectors with guidance for inspecting structural concrete in buildings and focuses on conditions that can lead to structural failure. Information on reported structural failures, generalized condition assessments, and accepted industry practices form the basis of the discussions and the inspection checklist.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE July 1991	3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE

Guide for Visual Inspection of Structural Concrete Building Components

5. FUNDING NUMBERS

FAD 89-08004
dated October 1988

6. AUTHOR(S)

Douglas E. Ellsworth and Keith Ginnado

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Construction Engineering Research Laboratory (USACERL)
P. O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER

TR M-91/18

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

USAEHSC
ATTN: CESHC-FB-S
Fort Belvoir, VA 22060-5516

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Proper inspection of building components can help reduce the likelihood of structural failures. Although inspectors at Army installations are responsible for monitoring the conditions of structural concrete, they currently have no organized method of inspecting this building component.

This report provides Army installation inspections with guidance for inspecting structural concrete in buildings and focuses on conditions that can lead to structural failure. Information on reported structural failures, generalized conditions assessments, and accepted industry practices form the basis of the discussions and the inspection checklist.

14. SUBJECT TERMS

Buildings
concrete
inspection

15. NUMBER OF PAGES

80

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

FOREWORD

This project was funded by the U.S. Army Engineering and Housing Support Center (USAEHSC) under Operations and Maintenance, Army (OMA) Funding Authorization Document (FAD) 89-08004, dated October 1988. The USAEHSC technical monitor was Mr. Michael Smith, CEHSC-FB-S.

The work was performed by the Building Research Council of the University of Illinois under contract to the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USACERL). Douglas Ellsworth was the Principal Investigator. Dr. Paul R. Howdyshell is Chief of USACERL-EM. The technical editor was Gloria J. Wienke, USACERL Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

CONTENTS

LIST OF FIGURES AND TABLES

Figures (Cont'd)		Page

Tables

GUIDE FOR VISUAL INSPECTION OF STRUCTURAL CONCRETE BUILDING COMPONENTS

1 INTRODUCTION

Background

Many buildings on military installations use reinforced concrete, in whole or in part, as the structural system. Proper inspection procedures, based on a visual investigation, can help identify deficiencies in concrete before they become critical to the overall stability of the structure.

Facilities engineers and inspectors at Army installations are responsible for monitoring the condition of concrete building components under the general requirements of Army Regulation (AR) 420-70, *Facilities Engineering, Buildings and Structures*.[1] However, no organized method currently exists for the visual examination of structural concrete systems and components in buildings.

Objective

This manual provides Army installation inspectors and facility engineers with background information and a systematic methodology for inspecting reinforced concrete buildings, focusing on deterioration conditions that can be seen and, more importantly, those conditions that can lead to a structural failure.

Approach

The information presented in this manual was gained by a review of documentation on deterioration conditions in concrete and of accepted industry recommendations and practices. A list of useful references can be found at the end of this report.

Scope

This manual does not prescribe repair techniques, nor does it address structural problems in concrete that do not manifest themselves visually. Through the presentation of basic design and technical information, this manual provides information to aid inspectors in the evaluation of deterioration conditions of concrete structures in buildings. This manual is primarily for evaluating building structures, and not structures such as bridges, storage bins, or mass concrete structures. A visual inspection of the deterioration of concrete structures reveals only generalized dangers. For a complete analysis of major structural deficiencies, the services of an experienced structural engineer are required.

---

[1] Army Regulation (AR) 420-70, *Facilities Engineering, Buildings and Structures* (Headquarters, Department of the Army, 17 November 1976).

2 CONCRETE BUILDING STRUCTURES

Deterioration in concrete is affected by the design of the structural system and its components, the construction techniques and activities of the construction site, and the range of experiences the structure is exposed to during its service life. Some deterioration conditions may stem from more than one of these categories. During the inspection, remember to check for all possible factors for a given deterioration condition.

Nature of the Material

Concrete is a heterogeneous manmade material that is constructed under a wide variety of conditions. As a composite material, its strength and durability rely on the interaction of its individual materials. A change in the composition of the concrete mix by an increase or decrease of the sand, water, gravel, or cement will greatly affect the quality of the concrete member. In most cases, concrete structures are built outside and are subject to the changes in temperature, humidity, and air movement characteristic of the geographic region in which they are constructed. Quality concrete construction provides for the particular requirements of geographic region, use, and structural needs. If concrete is used without considering these variables, deficiencies will result.

Concrete has significant resistance to compressive stress, but is relatively weak in tension. Tension zones result from bending and the capacity of the member can be greatly increased by placing stell reinforcing bars within this zone. (Figure 1).

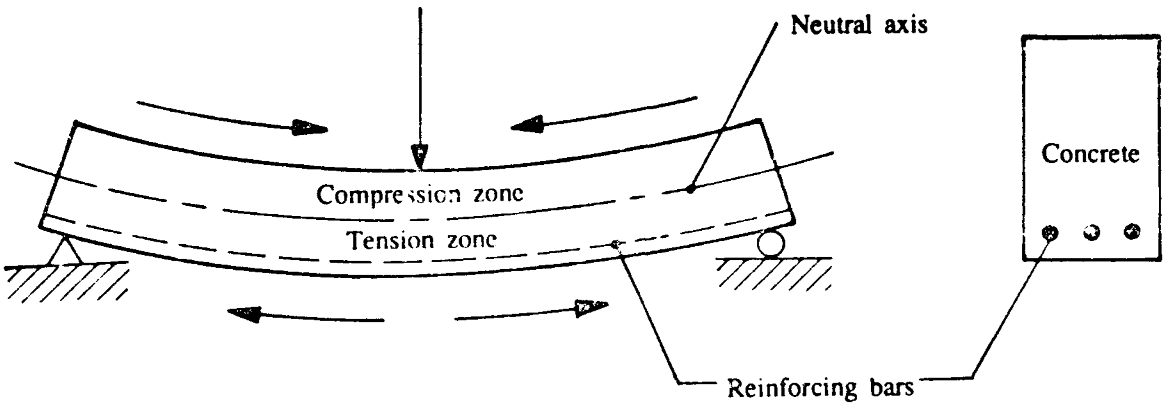
Columns are also subject to bending stresses and must incorporate reinforcing steel (Figure 2).

Nonstructural Deficiencies

Nonstructural deterioration is generally a surface deficiency resulting from conditions of the design, construction, or service life of the building. These deficiencies are not immediately critical to the performance of the structure, but they can cause further deterioration, which can eventually lead to structural deficiencies.

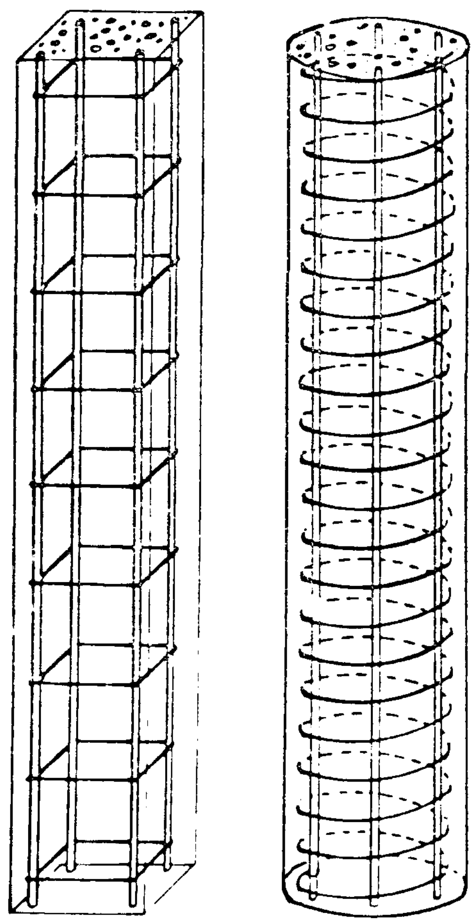
Structural Deficiencies

Structural deficiencies also develop due to the design, construction, and service life of the building. Structural deterioration in concrete indicates the breakdown of the material to a point that threatens the structural capacity of the members. Deterioration of this type is a critical factor in the continued use of the building.



(a) Beam (b) Beam section

Figure 1. Compression and tension zones in a typical reinforced concrete beam.



(a) Lateral ties (b) Spiral reinforcing

Figure 2. Lateral ties and spiral reinforcing in concrete columns.

Design Factors

Inadequate design considerations can cause deterioration in concrete. Correct material composition, proper anticipation of structural loading, and adequate provision for loads through sizing and placement of structural elements are necessary for strong and durable concrete structures. Sizing and locating structural members requires calculation of the anticipated loading to the structure and the location and character of that loading. The design of the shape and composition of the structural elements should take into consideration the beams, columns, and slabs, as well as the amount and location of reinforcing material and the specific cement, aggregate, water content, and admixtures that compose the concrete.

Construction Factors

Construction of concrete structures requires accurate fabrication of the concrete mix as specified by the design, adequate construction of forming devices to create the structural elements, and sufficient control of the environment under which the concrete members are created. Deficiencies in concrete can result from inadequate quality control, improper finishing techniques, and construction activities such as altering the mix proportions, prematurely removing forms, loading the concrete before it hardens adequately, and improperly operating equipment during construction.

Service Life Factors

During the life of the building, weathering and use contribute to deterioration of the concrete. Concrete elements are susceptible to deterioration from conditions that were not anticipated in the design or were not accommodated during construction: changes in occupancy, neglect, penetration of the structure by water and/or chemicals, and unforeseen stresses in the structure.

3 VISIBLE DETERIORATION CONDITIONS OF CONCRETE

Cracking

Cracks in concrete can never be entirely eliminated. While not all cracks are structurally significant, a qualified engineer should be consulted when there is any doubt. A general rule of thumb for the evaluation of cracking suggests that random patterns of cracks (Figure 3) with small magnitudes are frequently insignificant, while cracks running in definite directions with greater magnitudes can indicate a structural deficiency.

Map (or Pattern) Cracking

Map cracking, sometimes known as pattern cracking, is characterized by fine openings on the surface of the concrete. Map cracks generally result from a decrease in the volume of the material near the surface or an increase in subsurface material volume. Map cracking is structurally significant if the pattern follows the pattern of the underlying reinforcing steel or demonstrates separation of the concrete materials (Figure 3).

Single, Continuous Cracks

Single, continuous cracks with a definite direction and magnitude can indicate a structural deficiency. Cracks of this type are usually longitudinal, transverse, diagonal (Figure 4), vertical, or spiraling and will often continue to grow in depth and length (Figure 5) if the structural deficiency is not identified and corrected.

Cracks in concrete can be either passive or active. Passive cracks can be caused by construction errors, material shrinkage, variations in internal temperature, or shock waves. Active cracks can be caused by variations in atmospheric temperature, absorption of moisture, corrosion of the reinforcement materials, chemical reactions, settlement, or various loading conditions.

Cracking in concrete can be caused by design and detailing of reentrant corners in walls, precast members, and slabs; improper selection, sizing, and detailing of reinforcement; inadequate allowance for structural movement due to volume changes and material expansion; and the improper design of foundations. Cracks at reentrant corners, such as dapped-end beams and door and window openings, can occur due to inadequate diagonal reinforcing (Figure 6). Cracks resulting from material expansion occur due to inadequate provision for structural movement. Expansion joints are required to allow for lengthening and shortening structural members. Foundation movement due to inadequate bearing area on subgrade material will transfer crack-causing forces to the superstructure.

Nonstructural Deficiencies

Abrasion

Abrasion is the disintegration of the surface material because another material comes in contact with the concrete surface. Abrasion damage occurs most commonly in heavily trafficked areas. Too much water in the mix causes excessive bleeding, which brings fines and cements to the surface, weakening the durability of the surface material. Abrasion during construction can also result from heavy construction

Figure 3. Random pattern cracking of a wall.

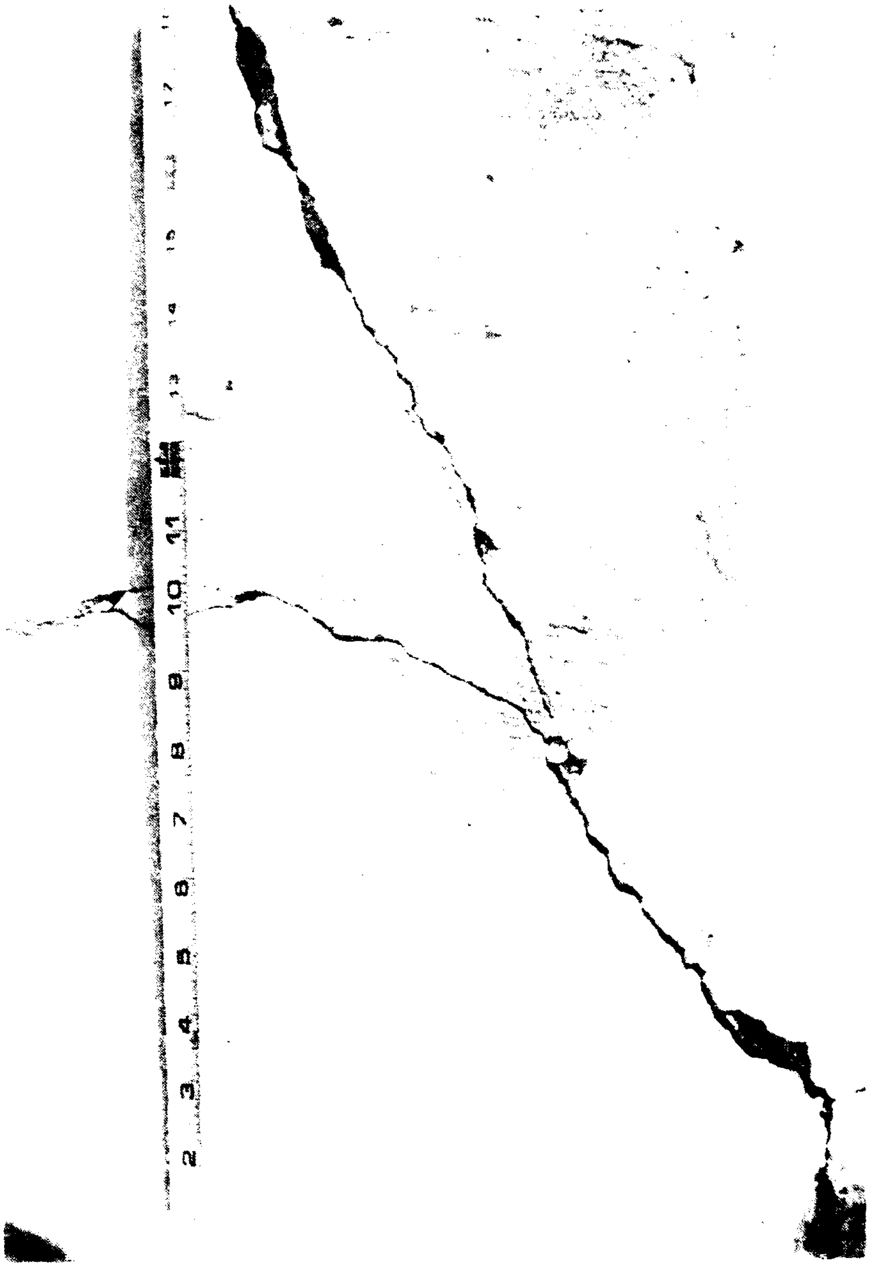
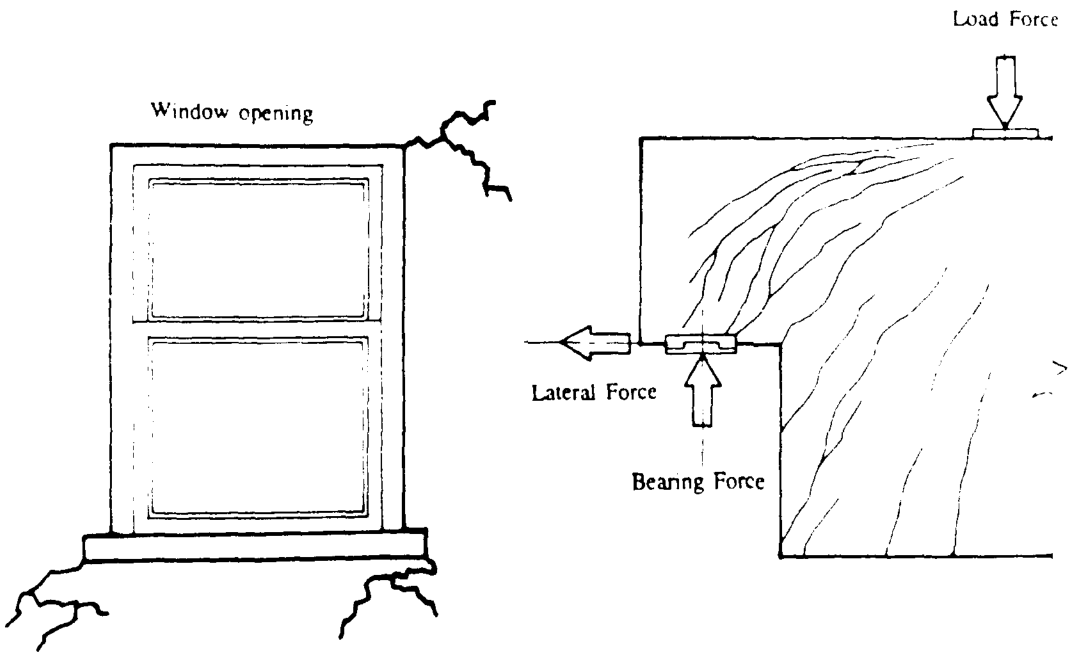


Figure 4. A diagonal crack in a wall.

Figure 5. Single, continuous cracking in beams due to corrosion of reinforcement.



(a) Cracks at reentrant corners.

(b) Cracks in dapped-end beams.

Figure 6. Typical crack patterns at reentrant corners and dapped-end beams.

equipment crossing areas not designed for abrasive conditions. Impact damage from collision with a concrete member can result in severe material loss (Figure 7).

Blistering

Bubble formation on the surface of concrete can result from an improper mix or inadequate vibration and consolidation of the plastic concrete during construction. Blistering creates subsurface air voids that can later spall off due to freezing and thawing.

Chemical Reaction Cracking

Chemical reactions within the concrete mix can cause cracking. Expansive reactions between the alkalinity of the curing concrete and the silica content in some aggregates can produce tensile stresses beyond the tensile strength of the concrete.

Figure 7. Abrasion/impact damage to a concrete column.

Cracking Due to Construction Practices

Inadequate form supports, improper concrete construction practice, and improper placement of construction joints contribute to cracks in concrete. Settlement of forms causes cracks because the concrete has not hardened enough to support its own weight. Construction joints placed at points of high stress can cause cracks.

Construction Overloading Cracking

Loads induced by construction often exceed the service loads for which the structure was designed. Loading during construction often occurs before the concrete has reached it: ıaximum strength. As a result, storing construction materials and operating heavy equipment can cause permanent cracking to the building structure.

Crazing

Excessive bleeding, premature troweling, excessive slump, and high water content in the surface layer of the concrete can result in crazing. Characterized by closely spaced fine cracks in the surface, crazing is primarily a nonstructural defect.

Discoloration

Discoloration of concrete can result from improper concrete mix specifications. Coloring agents or aggregates of differing alkalinity in the mix can cause color changes in the concrete material. A change in the color of the concrete from its intended color is generally not critical to the structural capacity, but the presence of stains can indicate moisture penetration. Rust stains from corroding reinforcement or from leaking pretension cables can indicate structural deficiency (Figures 8, 9, and 10).

Dusting

Dusting of concrete surfaces can result from a design specification that requires placing plastic concrete over a nonabsorptive surface. Excessive bleeding will cause water, cement particles, and fine aggregates to rise rapidly to the surface creating a weak surface layer that powders under any traffic and is easily scratched. If bleed water is present when finishing techniques are conducted, mixing excess water into the top surface of the concrete can cause dusting.

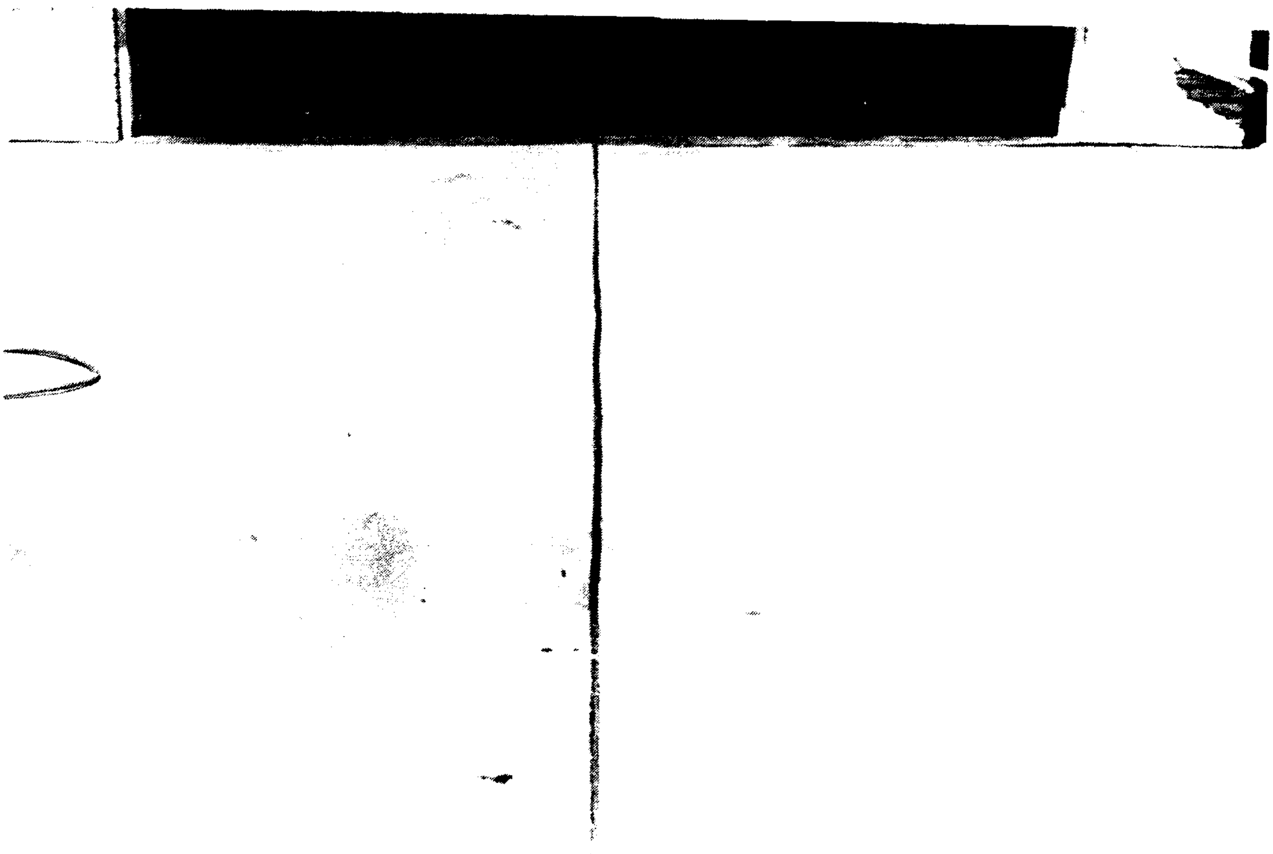


Figure 8. Discoloration of concrete paving.

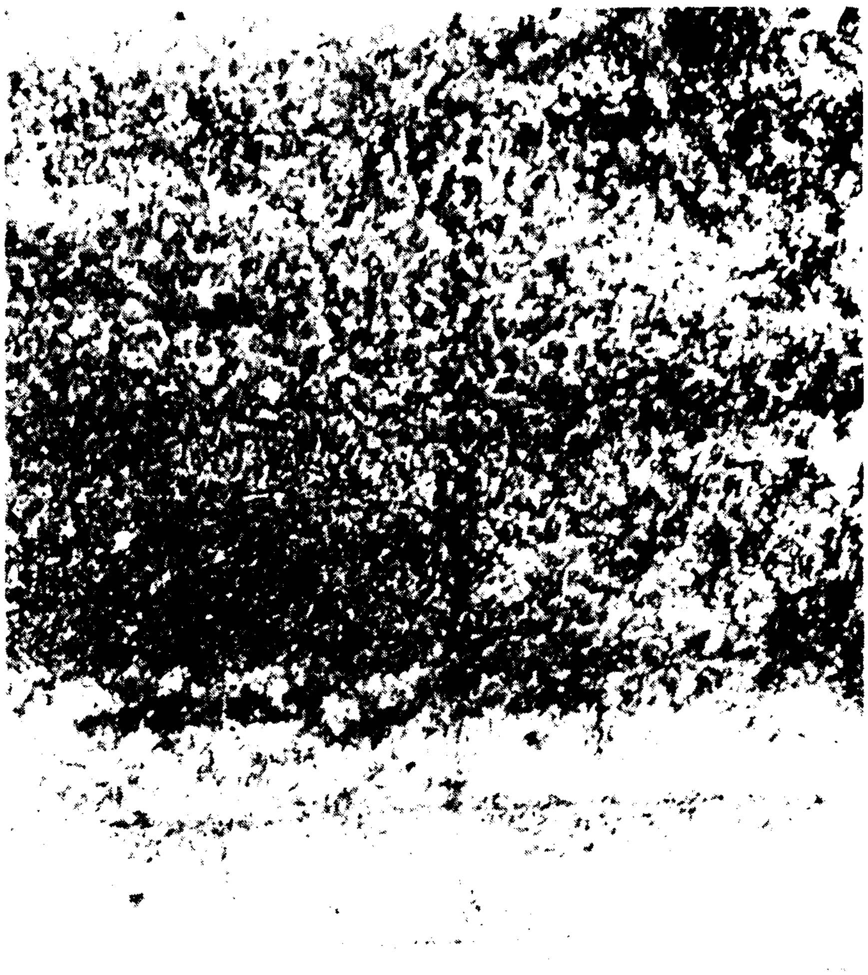


Figure 9. Discoloration of a concrete wall.

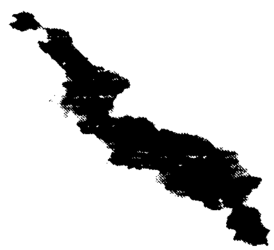


Figure 10. Discoloration due to grease leaking from the sheathing of a post-tensioning cable.

Efflorescence

Including aggregates in the mix that are reactive with the cement can cause a deposit of salts to form on the surface as bleed water rises to the surface and evaporates. Excessive amounts of water in the mix compounds the condition. Repeated wetting and drying of inservice concrete can leach salt deposits from the concrete mass and deposit them on the surface through cracks or other surface penetration (Figure 11).

Exudation

Exudation is a liquid or gel-like material discharged through openings or cracks in the concrete (Figure 12). Exudation can result from internal chemical reactions.

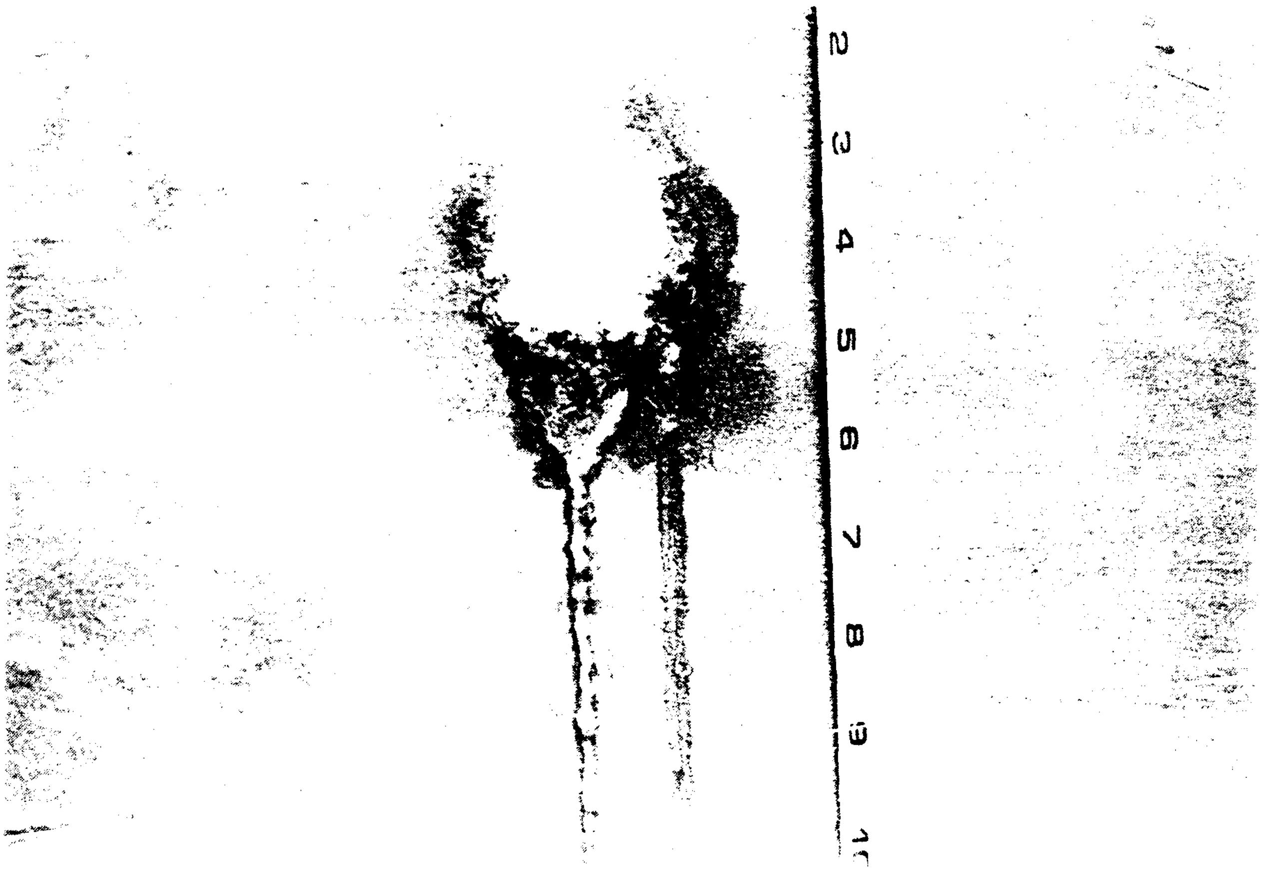


Figure 11. Efflorescence on a concrete wall.

Flaking

Flaking is the delamination of the surface concrete from the subsurface mass. It occurs because of improper construction practices or freezing and thawing of permeable concrete (Figure 13). High water content of the concrete mix can cause a concentration of fine aggregates and water at the surface. If finishing techniques are carried out while excess bleed water is still on the surface, delamination of the surface layer can later occur.

Flow (Lift) Lines

The placement of successive batches of concrete creates flow lines. An excessive passage of time between pours within the same member can cause flow lines (also known as cold joints). The cold joint between concrete batches permits water penetration that can cause damage due to freezing and thawing. Flow lines can also result from an excessive drop distance where material separation can occur during the placing of the concrete. Flow lines are primarily a construction-related deficiency.

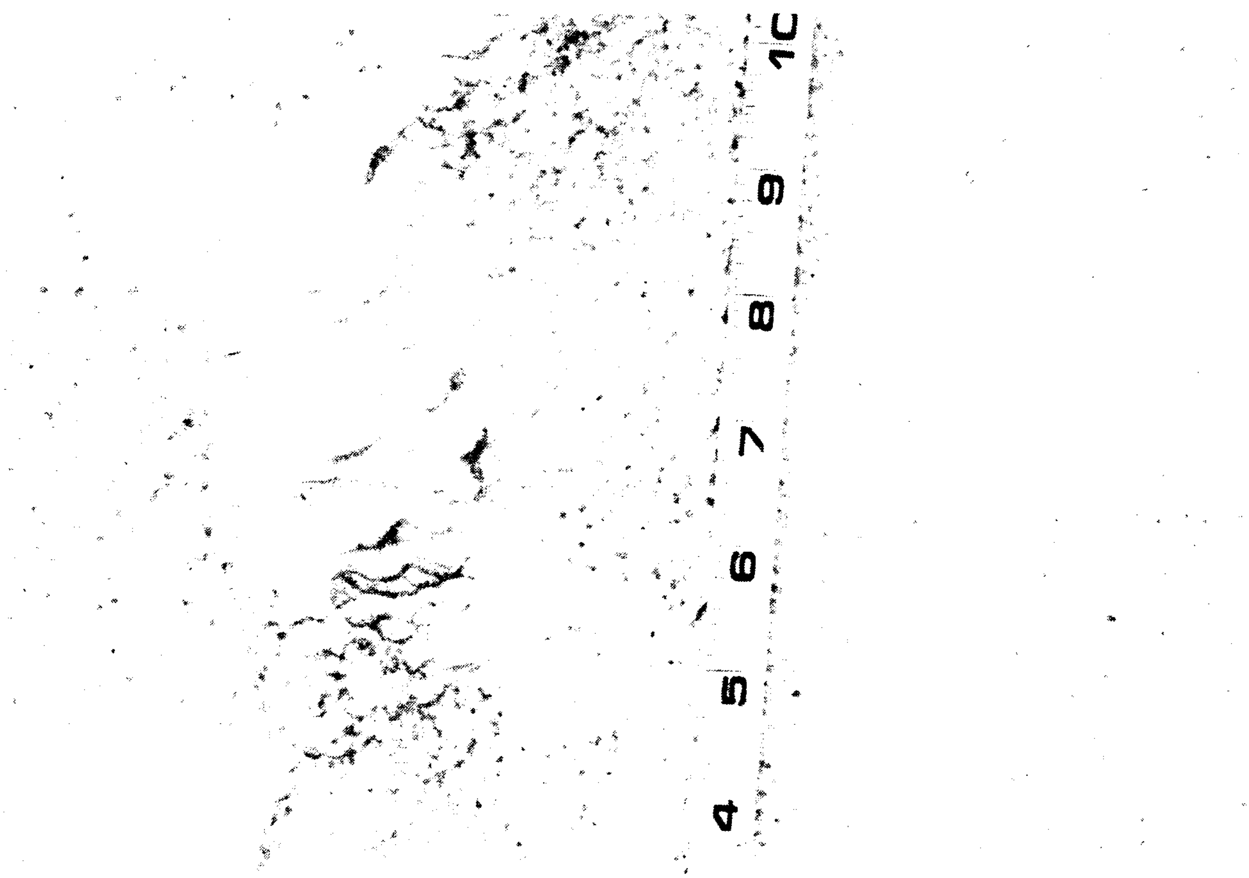


Figure 12. Exudation on a wall.

Honeycombing

Honeycombing is usually found in vertical rather than in horizontal surfaces and can occasionally extend completely through, resulting in a structurally unsound member (Figures 14 and 15). Honeycombing is caused by bleed water carrying fine aggregates to the surface, creating voids in the concrete mass. Bleed water will carry fine aggregates to the surface if the formwork is removed prematurely or if the concrete has an excessive water content. The surface can be rough with cavities up to several inches deep.

Peeling

Prematurely removing the formwork during construction can cause flakes of mortar to peel off the surface of the concrete, leaving coarse aggregates exposed.

Figure 13. Flaking of a concrete wall.

Figure 14. Light honeycombing of a wall.

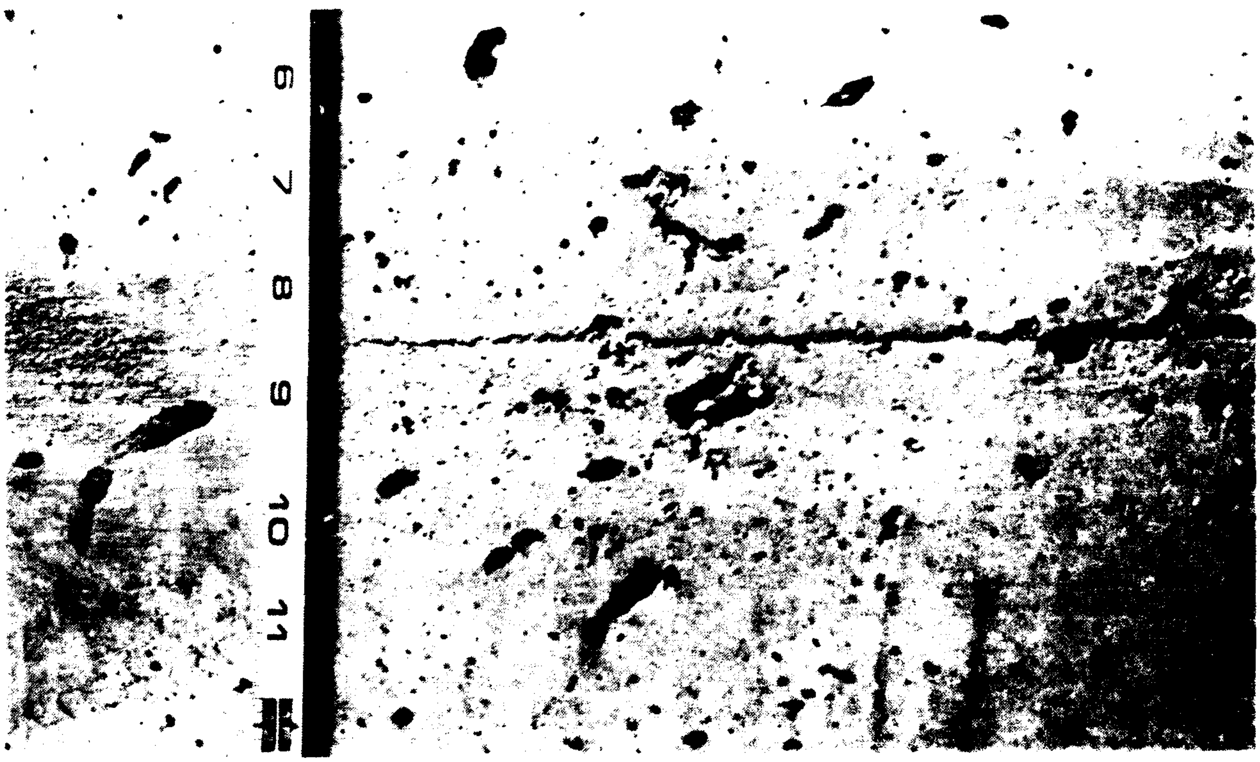


Figure 15. Major honeycombing of a wall.

Pitting

Small cavities in the surface of the concrete can result from corrosion or localized disintegration.

Popouts

Inadequate provision for structural movement can cause popouts (Figures 16 and 17). Restraining movement creates internal stresses that can result in conical depressions in the surface as the concrete relieves these stresses. Internal stresses caused by corrosion of reinforcement, cement-aggregate reactions, or internal ice crystal formations (from freezing water trapped within the concrete mass) can cause popouts. The shallow conical depressions in the surface of the concrete are classified by diameter: small is 0.4 in. (10 mm), medium is 0.4 to 2.0 in. (10 to 50 mm), and large is greater than 2 in. (50 mm).

Plastic Shrinkage Cracking

Plastic shrinkage cracks (Figure 18) are due to differential volume change in plastic concrete. Rapid water loss during hardening is the primary cause for cracks of this type. The surface layer of concrete will crack when moisture evaporates faster than it is replaced by bleed water. As concrete dries, it shrinks, and the subsurface material restrains the surface, causing cracks as the surface shrinks more rapidly than the subsurface concrete. Plastic shrinkage cracks are typically short, shallow cracks running in all directions over elements with large surface areas. Plastic shrinkage cracks range in length from only a few inches to several feet. They may be only a few inches or many feet apart. They may be only a few inches deep or extend the full depth of the member. Only in the worst cases is plastic shrinkage cracking a structural deficiency.

Sand Streaking

Bleed water can cause streaks to appear in the surface of concrete. As the bleed water moves upward in the forms, it carries sand upward, leaving a vertical trail on the surface.

Structural Deficiencies

Chemical Deterioration

Chemical deterioration is the separation of the material components of concrete as a result of chemical interaction. Including reactive aggregates in the concrete mix can cause chemical deterioration, as can attack by exterior chemicals. See Table 1 for a description of concrete deterioration resulting from action of chemical agents.

Corrosion Cracking

Corrosion of reinforcement in concrete can cause major cracking in concrete members (Figure 19). Rusting steel expands, causing cracks in the restraining concrete mass. When corrosion worsens, the concrete bond to the steel is lost. Tensile forces acting on such a deteriorated member can cause collapse (Figure 20).

Figure 16. Popout.

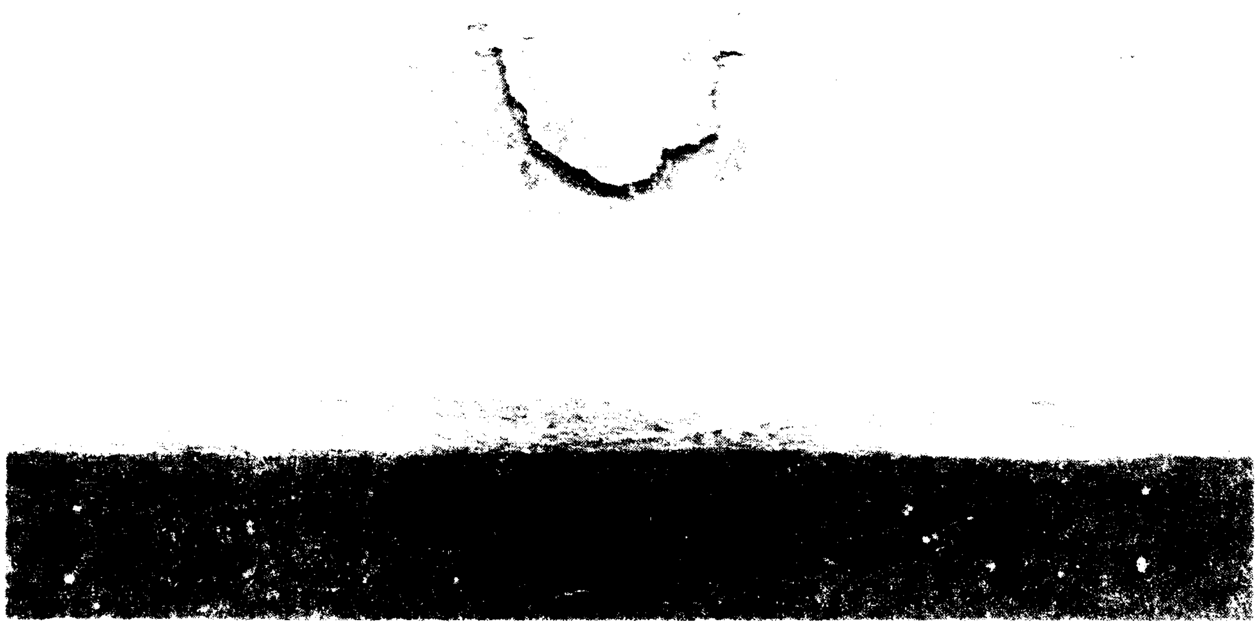


Figure 17. Potential popout in a beam.

Figure 18. Plastic shrinkage crack.

Table 1

Effect of Various Chemical Agents on Concrete*

ACIDS

MATERIAL	EFFECT ON CONCRETE
Acetic	Disintegrates slowly
Acid waters	Natural acid waters may erode surface mortar, but usually action then stops
Carbolic	Disintegrates slowly
Humic	Depends on humus material, but may cause slow disintegration
Hydrochloric	Disintegrates
Hydrofluoric	Disintegrates
Lactic	Disintegrates slowly
Muriatic	Disintegrates
Nitric	Disintegrates
Oxalic	None
Phosphoric	Attacks surface slowly
Sulfuric	Disintegrates
Sulfurous	Disintegrates
Tannic	Disintegrates slowly

SALTS AND ALKALIES (SOLUTIONS)

MATERIAL	EFFECT ON CONCRETE
Carbonates of Ammonia, Potassium, Sodium	None
Chlorides of Calcium, Potassium, Sodium, Strontium	None, unless concrete is alternately wet and dry with the solution
Chlorides of Ammonia, Copper, Iron, Magnesium, Mercury, Zinc	Disintegrates slowly
Fluorides	None except ammonium fluoride

Table 1 (Cont'd)

Hydroxides of Ammonia Calcium Potassium Sodium	None
Nitrates of	
Ammonium	Disintegrates
Calcium	None
Potassium	None
Sodium	None
Potassium permanganate	None
Silicates	None
Sulfates of Aluminum Calcium Cobalt Copper Iron Manganese Nickel Potassium Sodium Zinc	Disintegrates; however, concrete products cured in high pressure steam are highly resistant to sulfates

PETROLEUM OILS

MATERIAL	EFFECT ON CONCRETE
Heavy oils** below 35 °Baume	None
Light oils** above 35 °Baume	None—Require impervious concrete to prevent loss from penetration, and surface treatments are generally used
Benzine Gasoline Kerosene Naptha High octane gasoline	None—Require impervious concrete to prevent loss from penetration, and surface treatments are generally used

Table 1 (Cont'd)

COAL TAR DISTILLATES

MATERIAL	EFFECT ON CONCRETE
Alizarin Anthracene Benzol Cumol	None
Parafin Pitch Toluol Xylol	None
Creosote Cresol Phenol	Disintegrates slowly

VEGETABLE OILS

MATERIAL	EFFECT ON CONCRETE
Cottonseed	No action if air is excluded; slight disintegration if exposed to air
Rosin	None
Almond Castor China wood*** Coconut Linseed*** Olive Peanut Poppy seed Rape seed Soybean*** Tung*** Walnut	Disintegrates surface slowly
Turpentine	None; considerable penetration

FATS AND FATTY ACIDS (ANIMAL)

MATERIAL	EFFECT ON CONCRETE
Fish oil	Most fish oils attack concrete slowly
Foot oil Lard and lard oil Tallow and tallow oil	Disintegrates surface slowly

Table 1 (Cont'd)

MISCELLANEOUS

MATERIAL	EFFECT ON CONCRETE
Alcohol	None
Ammonia water (ammonium hydroxide)	None
Baking soda	None
Beer	Beer will cause no progressive disintegration of concrete
Bleaching solution	Usually no effect
Borax, boracic acid, boric acid	No effect
Brine (salt)	Usually no effect on impervious concrete
Buttermilk	Same as milk
Charge water	Same as carbonic acid; slow attack
Caustic soda	No effect on calcareous aggregate concrete
Cider	Disintegrates (see acetic acid)
Cinders	May cause some disintegration
Coal	Great majority of structures show no deterioration; exceptional cases have been coal high in pyrites (sulfide of iron) and moisture showing some action but rate is greatly retarded by deposit of an insoluble film; action may be stopped by surface treatments
Corn syrup	Disintegrates slowly
Cyanide solutions	Disintegrates slowly
Formalin	Aqueous solution of formaldehyde disintegrates concrete
Fruit juices	Most fruit juices have little, if any, effect as tartaric acid and citric acid do not appreciably affect concrete
Glucose	Disintegrates slowly
Glycerine	Disintegrates slowly
Honey	None

Table 1 (Cont'd)

Lye	See caustic soda
Milk	Sweet milk should have no effect, but if allowed to sour the lactic acid will attack concrete
Molasses	Does not affect impervious, thoroughly cured concrete; dark, partly refined molasses may attack concrete that is not thoroughly cured
Niter	None
Sal ammoniac	Same as ammonium chloride; causes slow disintegration
Sal soda	None
Saltpeter	None
Sauerkraut	Little, if any, effect
Silage	Attacks concrete slowly
Sugar	Dry sugar has no effect on concrete that is thoroughly cured; sugar solutions attack concrete
Sulfite liquor	Attacks concrete slowly
Tanning liquor	Depends on liquid; most of them have no effect; tanneries using chromium report no effects
Trisodium phosphate	None
Vinegar	Disintegrates (see acetic acid)
Washing soda	None
Whey	The lactic acid will attack concrete
Wood pulp	None

*Adapted from Portland Cement Association Publication ST-4-2 "Effect of Various Substances on Concrete and Protective Treatments, Where Required."

**Many lubricating and other oils contain some vegetable oils. Concrete exposed to such oils should be protected as for vegetable oils.

***Applied in thin coats the material quickly oxidizes and has no effect. Results indicated above are for constant exposure to the material in liquid form.

Figure 19. Vertical crack in a column.

Figure 20. Slab failure due to delamination of reinforcing steel from concrete.

Deflection Cracking

Deflection of concrete structural members can cause cracking in the member itself or in nearby elements (Figure 21). Member depth in the plane of the active force is critical to prevent excessive deflection. A deflecting concrete element can develop flexure cracks (see *Flexure Cracking* below) or can cause damage to elements adjacent to the deflecting member. Deflection cracking can result from construction overloads or from unanticipated loading from occupancy. Table 2 describes the maximum permissible deflection of concrete elements in relation to their spans.

Disintegration

Disintegration is the separation of concrete into its component parts. Disintegration results from chemical attack, abrasion, weathering, and erosion. Disintegration will continue to get progressively worse as long as the cause is present.

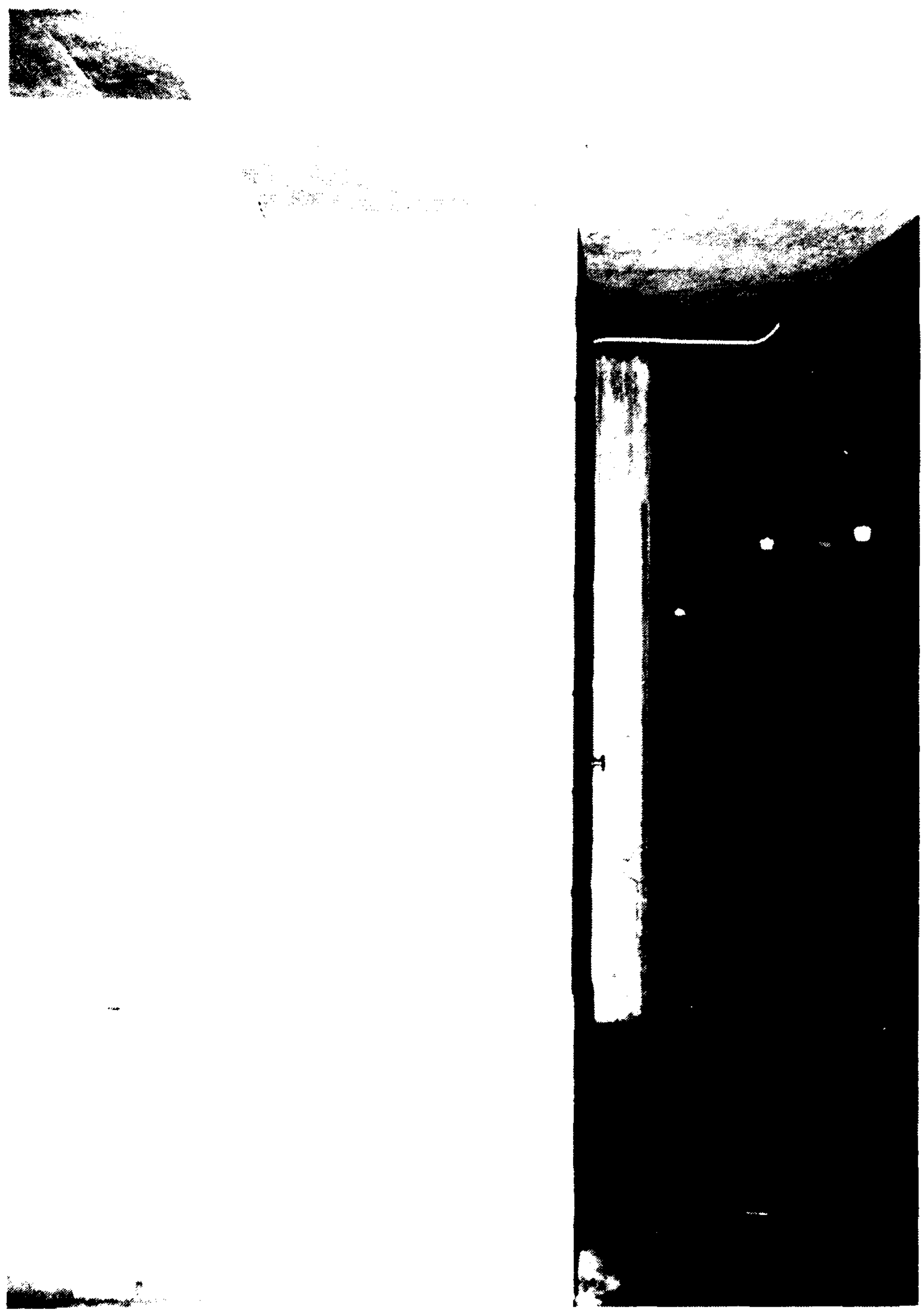


Figure 21. Cracking in a nonload bearing wall.

Distortion

If reinforcement is inadequate and details of structural members are poorly designed, deformation can result. A deformed member can lead to collapse if the distortion causes the member to be incapable of carrying the intended load. Distortion may continue to worsen, weakening the member to the point of collapse. The deformation of a concrete member from its intended shape can be caused by formwork deflection or shoring settlement during the construction phase. Foundation movement acting on concrete members from building use or from the environment can also cause distortion.

Erosion

Erosion occurs from liquids or solids coming in contact with the concrete. Continued abrasion causes a loss of material, exposing reinforcing or reducing the mass enough to critically affect the structure.

Flexure (or Moment) Cracking

Structural members designed without adequate stiffness permit flexure cracking. These cracks are also known as "moment cracks." Flexure cracks typically run parallel with the line of force acting on the member. In columns, flexure cracks are horizontal; in beams, flexure cracks are vertical. These cracks can occur in the middle region of the span in simply supported members, or over the supports in continuously supported members (Figure 22). In beams, members should have adequate depth to prevent excessive deflection. Flexural cracking can result from construction or service overloads.

Reinforcement Corrosion

Reinforcement corrosion is the deterioration of reinforcing material by chemical or electrical action resulting from contact with water and oxygen, and usually in the presence of chlorides. Penetrations in the concrete mass surrounding the reinforcing steel will permit the continued deterioration of the steel and its oxidation (Figures 23 and 24). Brown rust stains frequently appear on the concrete surface generally at a crack or other surface penetration. As the steel continues to deteriorate, the layers of rust expand, which causes strong internal forces that separate the concrete from itself and from the steel.

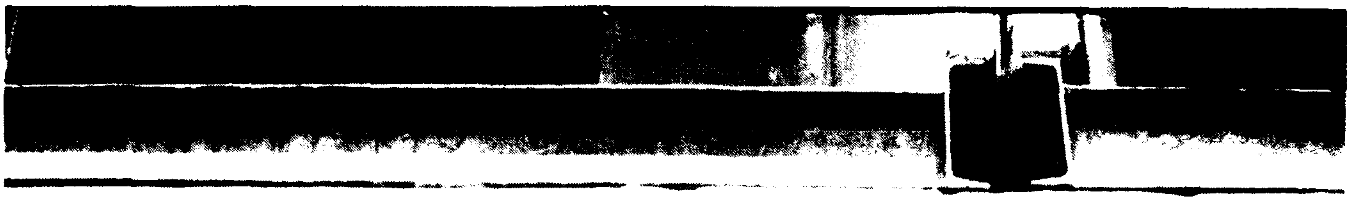
Adequate concrete cover must be provided to prevent corrosion of reinforcing steel. Concrete can be made less permeable to a certain degree, but adequate cover increases the impermeability of the material. The minimum thicknesses of cover according to ACI 318-89[2] are as follows:

- Footings and other principal structural members cast against the ground, 3 in. (7.5 cm). Concrete cast in forms and later in contact with the ground or exposed to the weather, 2 in. (5 cm) for bars larger than No. 5; 1 1/2 in. (3.8 cm) for No. 5 bars and smaller. (No. 5 bars are 5/8 in. or 16 mm in diameter.),

- Concrete not exposed directly to the ground or to weather, 3/4 in. (1.9 cm) for slabs and walls; 1 1/2 in. (3.8 cm) for beams and girders, and

- Column spirals or ties, 1 1/2 in. (3.8 cm), and at least 1/2 times the maximum size of coarse aggregate.

[2] *ACI Manual of Concrete Practice, 1990, Part 3*, "Building Code Requirements for Reinforced Concrete (ACI 318-89) and Commentary - ACI 318R-89" (American Concrete Institute [ACI], 1990).



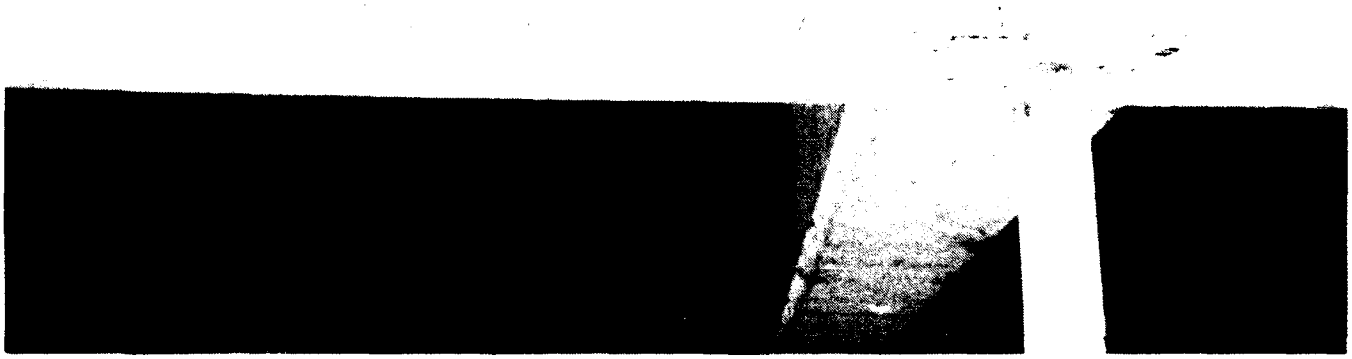


Figure 22. Flexure cracking at midspan of a beam.

Figure 23. Severe spalling of concrete due to corrosion of reinforcement.

Figure 24. Reinforcement corrosion of concrete beams.

Scaling

The most common form of scaling is due to weathering. Flaking or peeling away of the surface material is caused by freezing and thawing. Light scaling is characterized by the loss of surface material only (0.2 to 0.39 in. or 5 to 10 mm). Medium scaling is characterized by the loss of surface material and the underlying coarse material (0.2 to 2 in. or 5 to 50 mm) with coarse aggregate clearly exposed. Very severe scaling is the loss of surface material and the loss of coarse aggregate particles. The loss of structural material can lead to inadequate load bearing capacity or exposure of the reinforcing steel to corrosive forces (Figures 25 and 26).

Shear Cracking

Inadequate reinforcing at high shear locations permits cracking in columns, beams, and slabs. The design of these structural members must provide the proper amount and location of reinforcing at beam and column ends and at their interface with slabs. Shear cracking is typically a diagonal crack occurring near the ends of concrete members where forces are acting in opposite directions in the same region. Shear cracking also can result from construction overloads, from unanticipated service loads, or from improper placement of reinforcing. High shear zones occur at member ends and interfaces with other structures. Shear cracking can be caused by horizontal movement, such as by an earthquake, or by vertical movement from environmental loads. Overloading from occupancy also can induce shear cracking (Figure 27).

Spalling

Active spalling occurs as a result of variations in internal temperatures, corrosion of reinforcing steel, chemical reactions, and freezing and thawing, and can continue to spread. Passive spalling is the result of a shockwave, impact, or a single internal temperature change and usually will be dormant after the cause is arrested. Passive spalling can be repaired, but active spalling indicates a greater, potentially dangerous, structural problem. Spalling is characterized by circular or elliptical depressions in the concrete surfaces. A small spall is not greater than 0.787 in. (20 mm) in depth nor greater than 5.9 in. (150 mm) in any dimension. Large spalls are generally more than 0.787 in. (20 mm) in depth and greater than 5.9 in. (150 mm) in dimension. Joint spalls occur along joints in concrete members. Spalling allows water to penetrate the concrete, which will continue to deteriorate if the problem is not eliminated (Figures 28 and 29).

Stratification

Stratification is the separation of concrete materials into their component parts during the placing of concrete. A high water content greatly influences stratification. The heavier concrete components settle to the bottom portion of the member, forcing smaller particles to the top. Stratification also is evident when successive batches differ in appearance. An uneven distribution of concrete materials or layers that have not properly bonded can alter the structural capacity and performance characteristics of the concrete. Other problems (such as moisture penetration, cracking, severe efflorescence, or rusting) occurring along with stratification can indicate a structural deficiency.

Figure 25. Severe scaling of a concrete wall.

Figure 26. Scaling of a concrete pavement.

Figure 27. Shear failure of a concrete girder.

Figure 28. Flaking and spalling of concrete.

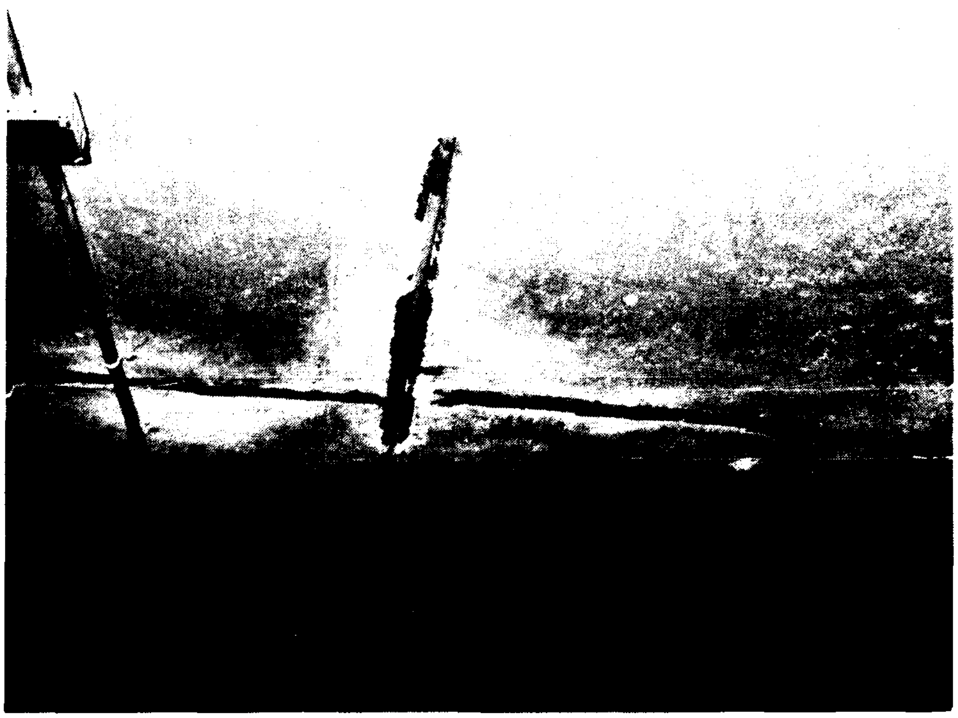


Figure 29. Spalling of the concrete due to inadequate cover depth.

4 OVERALL BUILDING INSPECTION

To make a thorough and accurate inspection, the inspector must become familiar with the building's structural design and present condition. As the inspector, you should obtain and study all available construction documents to help you identify the major structural members, modifications to the structure, changes in use, or problems that have not been noted in previous inspections. You should study the following documents before making an inspection:

1. As-built drawings—architectural, structural, mechanical, and foundation plans,
2. Construction specifications with addenda,
3. Soils and material test reports,
4. Pertinent correspondence,
5. Documentation pertaining to performance, defects, maintenance, and alterations, and
6. Prior inspection reports.

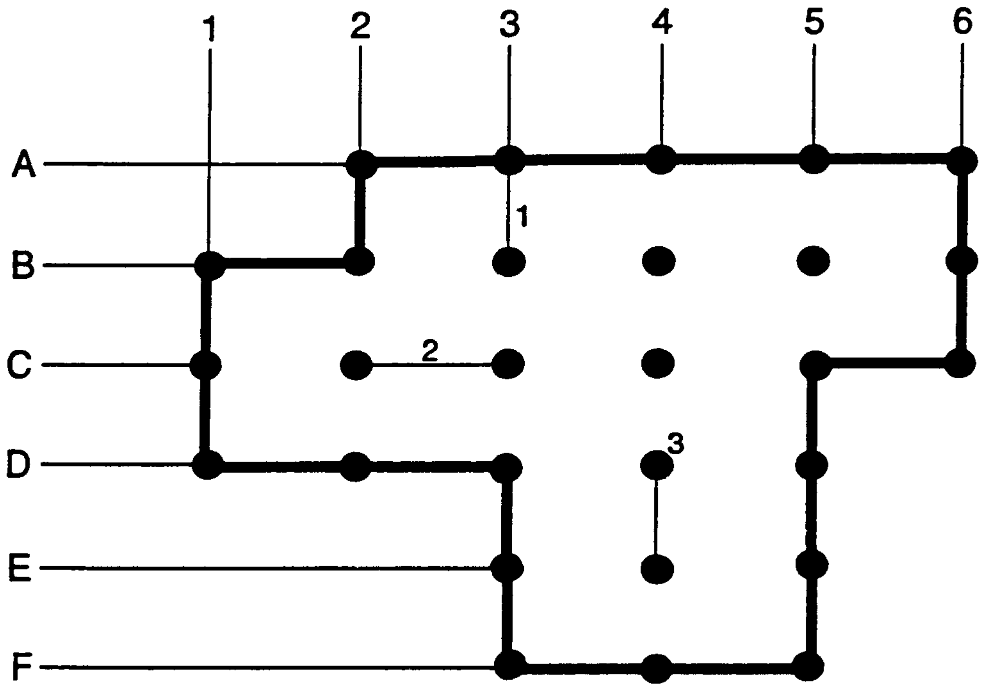
Before beginning the inspection, prepare sketches of the floor plan and structural frame of the building. As-built drawings will help you prepare these sketches, but you should measure actual spans of girders, beams, and slabs, record dimensions on the sketch, and verify the dimensions against the as-built drawings. Note on the Inspection Checklist (Appendix) any deviations in actual measurements when compared with as-built dimensions. Prepare a separate sketch for each floor of the building. Standard practice for this type of sketch uses the convention of numbers along the horizontal axis (left to right) and letters along the vertical axis (top to bottom). A letter-number combination is used to designate a specific beam, column, or bay where a problem is identified during the visual examination. If you find a problem during the inspection, write the location on the Inspection Checklist using the letter/number designation.

To conduct a thorough visual inspection, you may often need ladders or other special equipment to reach difficult areas. All safety measures should be used. A list of common tools and equipment that will be helpful during the inspection is included in Table 3.

Site Inspection

The condition of a concrete structure can be affectd by the site's environment, soil characteristics, water drainage, proximity to water or chemical waste, and the activities that take place on the site. Corrosive elements in the soil from buried chemicals can react strongly with concrete at grade level or below. The concrete surface will suffer deterioration from contact with these corrosive elements.

Study existing soil reports to become familiar with the composition and bearing stresses pertaining to the building. Soil characteristics include the soil's bearing capacity, the horizontal pressure exerted by the soil, the possibility of soil-borne corrosive elements, and the frost depth in the region. If the soil bearing capacity was not properly accounted for during the original construction, differential settlement of the foundation may occur. This settlement can cause failure in the superstructure. Check for grade level changes near the foundation. If the foundation footings do not extend below the frost depth, ground heaving could result.



PLAN (STRUCTURAL FRAME)

EXAMPLES OF DESIGNATION USAGE:

1. BEAM (A3-B3), IF A 2ND FLOOR WOULD BE (A3-B3,2), ETC.
2. BEAM (C2-C3)
3. COLUMN (D4)

Figure 30. Plan Structural Frame.

Table 3

Inspection Tools

Standard Tools:
- 100-foot measuring tape and folding rule
- inspection mirror with a swivel head
- calipers
- plumb bob
- straight edge
- feeler gauges
- binoculars
- camera and film
- screwdriver
- heavy duty pliers
- flashlight
- pocket knife
- wire brush
- magnifying glass
- crack comparator
- level
- clipboard
- chalk

Special Equipment:
- ladder
- "cherry picker"

Soil Movement

Because one surface of basements and retaining walls is buried beyond view, note any unusual characteristics, such as large cracks, stains, storage tanks, large trees, etc., on a sketch and compare to conditions on the other side of the wall. Carefully check for soil displacement around the building base and retaining walls. Soil movement under slabs, piers, and foundation walls can cause severe movement in the foundation structure. When this movement is transferred to the superstructure, torsional and shear forces can overtax the concrete members. Below is a list of causes for soil movement:

- Failure in load-bearing soil strata,
- Soil consolidation,
- Variation in moisture content of soil,
- Soil compaction,
- Slope instability,
- Heave due to frost,
- Earth tremors and earthquakes,
- Soil shrinkage due to heating,
- Soil swelling due to freezing,
- Mineral extraction (tunneling),
- Soil compaction due to vibration,

- Settlement due to collapse of cavities,
- Movement due to construction on or near the site,
- Subsurface erosion,
- Soil swelling in clays caused by moisture, and
- Soil erosion from faulty drains or water supply.

During construction, basement and retaining walls are subjected to horizontal pressures from the soils pushing against the vertical wall surface. Proper bracing must be provided during construction to ensure adequate lateral support to counteract this force when it is most critical. Inadequate bracing will result in walls that are unstable and not plumb.

Water Drainage

Water should drain away from the building's foundation. Water-saturated soil in contact with the foundation wall increases horizontal pressure. Moisture penetration can cause corrosion of the reinforcing and will contribute to freeze/thaw deterioration. Algae and fungi can begin to grow on the surface of the concrete. Areas where water problems could be affecting the building's structure should be noted. Check the ground where the soil meets the wall for evidence of ponding or erosion.

If an active body of water, such as a stream, underground spring, or run-off from a downspout passes near the building, erosion could result. Soil erosion can lead to structural collapse. Moving water erodes soils and subsoils from around the base of the structure and can abrade the concrete surface material.

Chemical Waste

In a similar manner, chemical waste leaking from a storage tank or from a dump site will corrode the concrete and reinforcing steel, weakening the structure significantly. Review site drawings to determine the existence of any subterranean chemical tanks. Examine the site for surface level tanks and check the area in the immediate vicinity for leakage.

Site Activities

Site activities can also contribute to the deterioration of the concrete structure. Vibration from passing heavy vehicles (trains, trucks, or highway traffic) can cause stresses in the concrete for which it was not designed. Around busy vehicular areas (i.e., loading docks, warehouse storage bays, etc.), the possibility for impact damage is significant. Columns and walls are highly susceptible to collision, which can cause deterioration of the surface of the member, expose reinforcing steel to the weather, or cause structural cracks.

Exterior Envelope Inspection

The exterior envelope includes all building materials that are exposed to the outside environment. Walls, windows, doors, and roofs are the most commonly accepted components of the exterior envelope. In the overall inspection of this part of the building, keep in mind the possible deterioration conditions resulting from exposure to the year-round environment. Water is the biggest problem in a concrete structure; therefore, concrete roof structures and structural elements located at the periphery of the building envelope (such as spandrel beams and exterior columns) are most susceptible.

Walls

Problems identified on the exterior walls can translate to the interior. The exterior walls can be load-bearing or have a nonstructural veneer. In a veneer system, a deficiency on the exterior can indicate a structural deficiency with the supporting members of the frame (e.g., if a beam in a concrete frame deflects, it can crush the veneer surface below it). In a load-bearing wall, a deficiency on the exterior can be directly repeated on an interior surface.

Inspect the walls to see if they have remained plumb or if there is any noticeable bulging. Pressures exerted by the structural frame can show up as deflection or expansion and can cause the exterior walls to deform, crack, or lose their vertical orientation. These changes indicate potential structural problems. If there is evidence of bowing in the exterior walls, the interior must be checked to determine if the wall has separated from any connections, thus increasing the wall's unbraced length.

Note any surface defects. Note any cracks and determine whether the cracks are minor surface cracks or those that could be traced to a structural element. Sometimes a problem can be identified by the pattern of a crack.

Openings

Window and door openings offer a range of possibilities for deterioration since the surface of the wall has been interrupted for an opening that sometimes is large. Loads that would normally pass downward through this part of the wall must be diverted around the opening and back toward the ground. Problem areas are found at lintels, sills, and thresholds where forces can distort the frame. Check openings for squareness and verify the size of all major openings. Check for diagonal cracks at the corners and evidence of water penetration that can reach the reinforcing steel in the structure. Windows and doors are also subject to abrasion and impact from whatever passes through them. Look for damaged edges and signs of impact that may have weakened the door or window frame.

Roof

Inspect the roof for evidence of ponding water, major depressions in the surface of the roof, cracks, and other defects. Ponding water increases the concentrated load in the area where it occurs, causing stresses on the structure for which it was not specifically designed. Depressions in the roof may indicate an impact blow that occurred during construction or during the service life of the building. In such cases, the structure immediately below these areas of the roof should be inspected carefully during the Component Inspection (see Chapter 5).

Foundation and Piers

Note any cracks in foundations in areas near downspouts, at corners of buildings, or where major structural supports such as columns meet the foundation walls or piers. Check piers to make sure that they have remained plumb. Note any areas that appear to have settled.

5 COMPONENT INSPECTION

The purpose of the Component Inspection is to focus on specific building elements for condition evaluation. In the Overall Building Inspection, problem areas were defined and the general condition of the building was determined. This section is devoted to a critical evaluation of the structural elements of the building, with particular attention given to those components identified in the previous section as potentially dangerous. In general, photograph, record, and prepare detailed annotated sketches of the following major defects:

- Cracks—width, depth, length, location, and pattern,
- Spalls—and other surface defects recorded where they occur,
- Corrosion of Rebars—extent of corrosion and amount (%) of lost cross-section,
- Loose, corroded, or otherwise defective connectors for precast concrete elements, and
- Deformations under loads (permanent or movements). Out-of-verticality of columns and other misalignments.

Walls

Reinforced concrete walls are typically used in buildings as foundation or load-bearing walls, usually with a veneer surface. Common defects in reinforced concrete walls include cracking, spalling, deviation from plumbness, and rust stains. If cracks or fractures are present at intervals along a reinforced concrete wall, they may have been caused by shrinkage or movement due to moisture, combined with a lack of movement joints. Diagonal fractures in concrete walls usually indicate differential foundation or support settlement. With respect to plumbness, general deviations from the vertical and horizontal in excess of about 1 ft in 250 ft are likely to be noticed.

A general overall inspection of the interior spaces should check the condition of walls, floors, ceilings, partitions, and openings to see if they are out of square. Brittle finishes such as plaster and paint will show distress from horizontal and vertical movement.

Inspect interior walls. Look carefully at floors and ceilings, noting where sagging, cracks, and discoloration may have resulted from structural deficiency. Check for cracks where floors and ceilings intersect walls. Note if there is any evidence of movement. Does a floor slab, for example, appear to have dropped below its original location? If the concrete walls, ceilings, or floors are discolored, look for signs of water infiltration. Bulging or cracks on interior walls may indicate potential structural damage. Severe water penetration resulting in large stains should be checked by an engineer.

Foundations

Thoroughly investigate the basement of the building to evaluate the stability of the foundation walls. Cracks in the walls can result from a number of soil-related problems. The location and severity of the cracks will help identify the specific cause of distress.

If the building is constructed on piers rather than foundation walls, check the piers for alignment and plumbness. Also inspect the column connection at the pier for possible corrosion from moisture or aggressive soils.

A foundation or pier failure can cause cracking and excessive deflection in the superstructure. Foundations should extend below the frost depth to avoid displacement by heaving soil.

Heaving soil makes a basement floor convex and causes cracks parallel to the edges of the foundation wall (Figure 31). If a floor is free of the wall but not free of a column, a concentric crack will form around the column (Figure 32). If a floor on a heaving soil is bound to a wall at one point, the upward thrust causes the wall to crack at that point (Figure 33). If a wall is settling, cracks occur at each end of the portion that is moving downward (Figure 34). Differential settlement occurs when the magnitudes of the loads on two intersecting walls are considerably different (Figure 35). Lateral movement of a foundation wall caused by soil pressure results in diagonal cracks at each end and vertical cracks in the center area (Figure 36). A single vertical crack denotes upward movement of a foundation. However, if the crack is very narrow, it could be drying, shrinkage, or thermal crack (Figure 37).

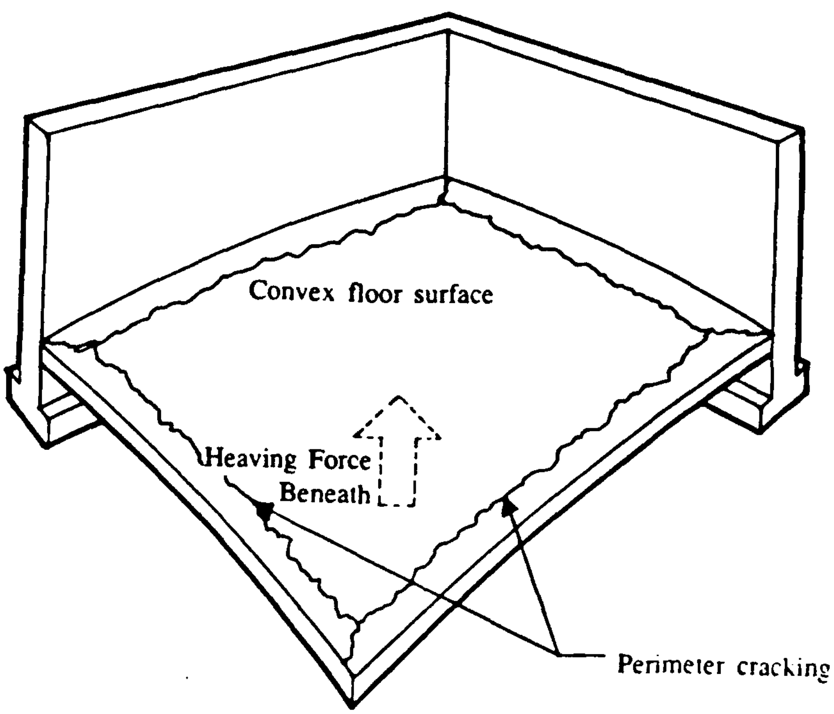


Figure 31. Heaving soil under a floor slab causing a convex floor and perimeter cracking.

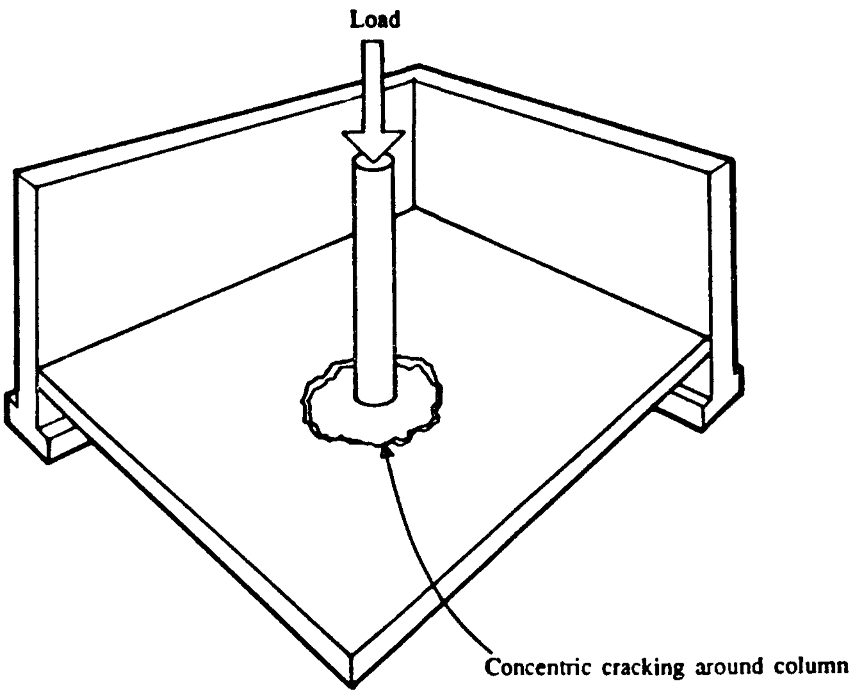


Figure 32. Slab movement around a column causing concentric cracking.

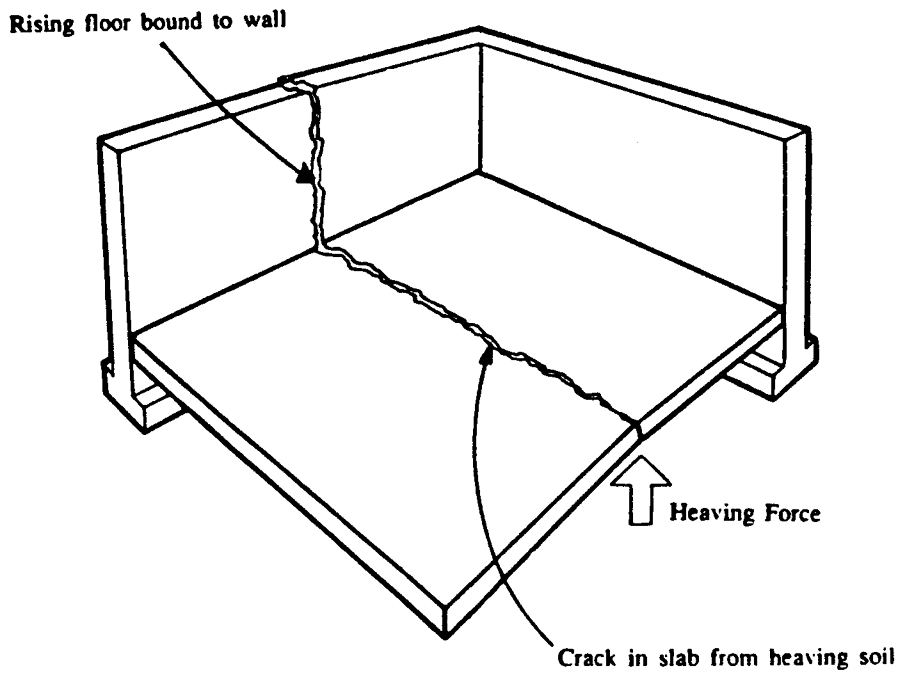


Figure 33. Heaving soil under a floor slab causing cracks in concrete wall and slab.

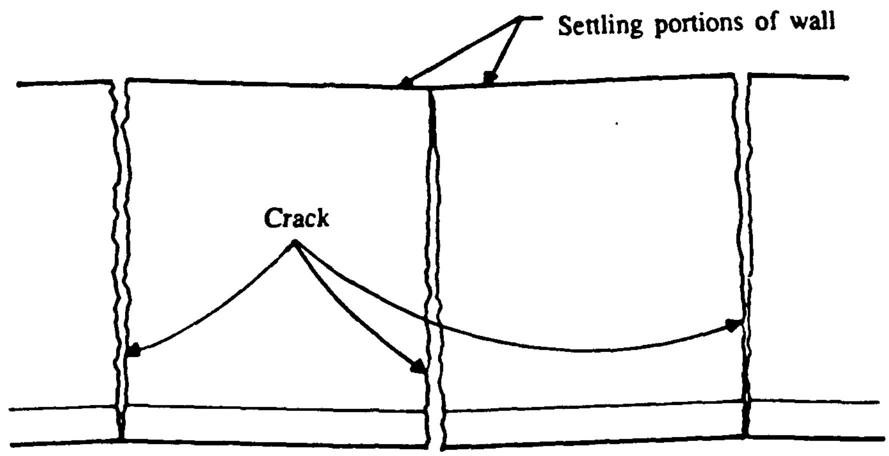


Figure 34. Foundation wall settlement.

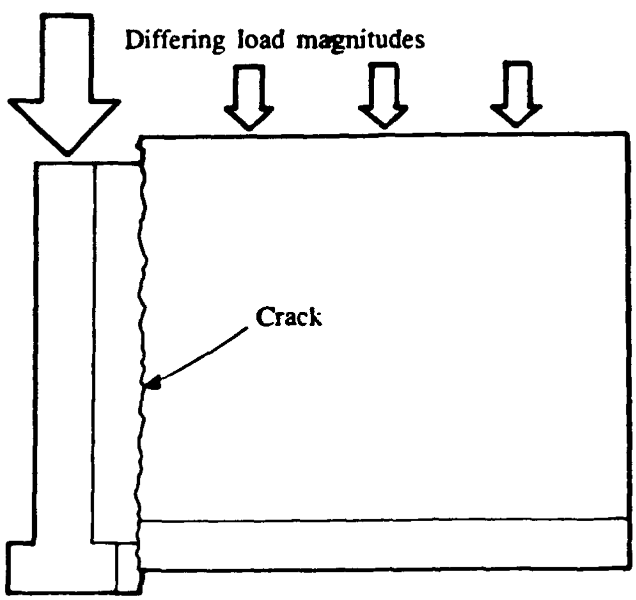


Figure 35. Differential settlement in a foundation wall.

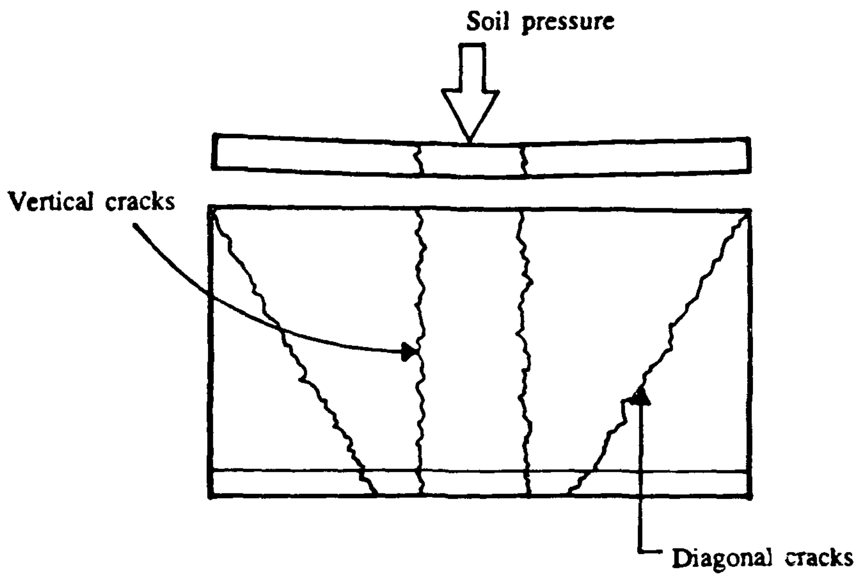


Figure 36. Lateral movement of a foundation wall.

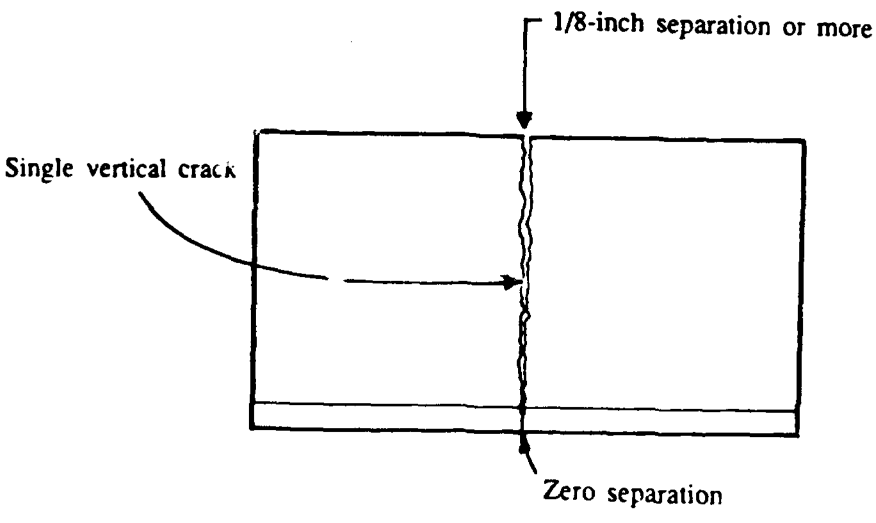


Figure 37. Upward movement of a foundation wall.

Columns

Columns are the primary vertical elements in a structural frame and are usually in compression. Columns can extend for one story or can connect many stories transferring loads downward. Deterioration in columns results from overloading, impact, abrasion, or seismic actions. Impact from heavy equipment and trucks can be a common cause of deterioration in high traffic areas. Large dead loads above a column can cause bulging or crushing which indicates localized compressive failure.

Concrete columns support compressive loads. Due to the monolithic placement of floors and columns, columns are also subject to a bending force known as moment force. To counteract this force, lateral steel reinforcing ties are used to hold vertical bars in place and provide lateral support. Spiral ties are also used to provide lateral support in columns (Figure 2). Because columns play such a crucial role in the support of the structure, their integrity must be maintained. Investigate even minor defects thoroughly.

Inspect along the columns for alignment, plumb, impact damage, and cracking. Check the connections at the base and capital for cracks or signs of crushing or distortion. Verify section sizes at critical areas, such as at midspan and ends.

Beams and Girders

Beams and girders transfer the load, through bending and sheer, to the column and thus to the ground. A 1 1/2-in. (3.8 cm) concrete cover over this reinforcement should be maintained to prevent corrosion of the steel by the environment. Figure 38 shows types of cracking in concrete beams and girders.

Bending induces both tension and compression forces that differ depending on the location in the span (Figure 1). Reinforcing steel is placed in the member in areas subjected to tensile forces; generally the lower parts at midspan and the upper parts over supports.

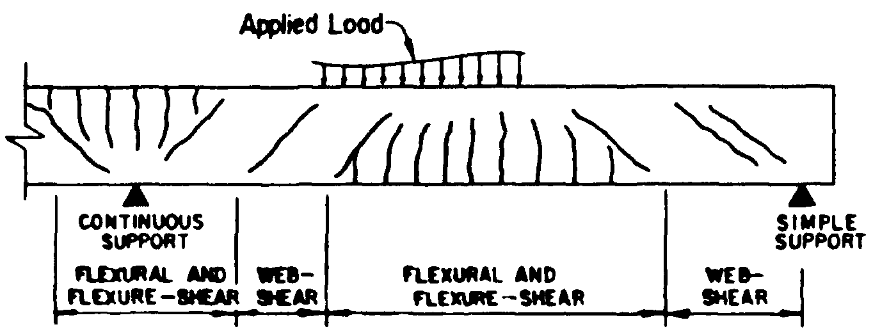


Figure 38. Types of cracking in concrete beams and girders.

Beams and girders must be checked for deflection, cracking, and other surface defects that may indicate structural deficiencies. For horizontal members, a local slope or deflection greater than 1/100 (1/8 in./ft or 9.6 cm/m) would be clearly visible. A deflection-to-span ratio of more than about 1/240 would also be visible. Table 2 shows the maximum permissible measured deflections as per ACI 318-89. The actual critical ratios depend on the function of the building. Similarly, other defects may be acceptable damage in one region or type of building and unacceptable in another (industrial vs. barracks). Excessive deflection can also be detected by damage to partitions and/or glazing below the member. These deflections may be the result of several factors related to design, construction, and service conditions. The original design may not have provided for adequate depth of a member. Or, the structural system may have been constructed with inadequate depth. Thus, compare span/depth ratio with the design criteria for a preliminary check (Table 4). Another construction-related fault is that the tensile reinforcement may have been placed out of position. Unfortunately, this cannot be detected without the use of nondestructive testing (NDT). During the service life of a building, the occupancy type and requirements may change; thus, the structure may be subjected to loads greater than those considered in the original design.

Table 4

Minimum Measured Thicknesses Unless Deflections Are Computed

	SIMPLY SUPPORTED	ONE END CONTINUOUS	BOTH ENDS CONTINUOUS	CANTILEVER
	Members not supporting or attached to partitions or other construction likely to be damaged by large deflections			
Solid one-way slabs	l*/20	l/24	l/28	l/10
Beams or ribbed one-way slabs	l/16	l/18.5	l/21	l/8

* Span length l is in inches.

Values given shall be used directly for members with normal wight concrete (w_c = 145 pcf) and Grade 60 reinforcement. For other conditions, the values shall be modified as follows:

(a) For structural lightweight concrete having unit weights in the range 90-120 lb/cu ft, the values shall be multiplied by (1.65-0.005 w_c) but not less than 1.09, where w_c is the unit weight in lb per cu ft.

(b) For f_y other than 60,000 psi, the values shall be multiplied by (0.4 + f_y /100,000).

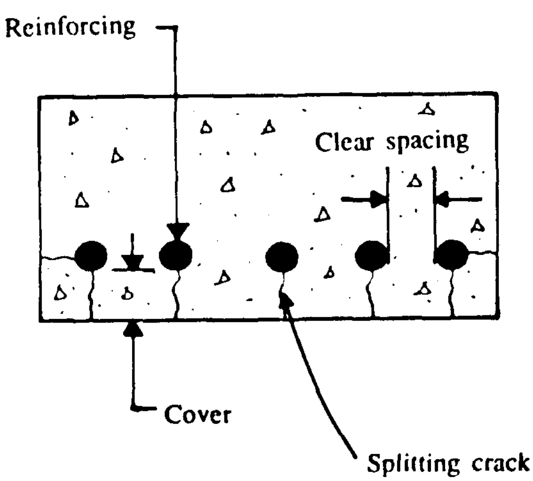
Adapted from *ACI Standard/Committee Report (318/318R-89).*

Cracks that are structurally significant will take a couple of different forms. Vertical or slightly inclined cracks are flexural, and flexure shear, usually occurring at the point in a member of highest moment, such as at midspan or over a support in a continuous member (Figure 22 and Figure 38). They may occur due to faulty design, insufficient reinforcement, inadequate depth, thermal movement, shrinkage around the stirrups, or overloading. Compare the span/depth ratio with the design criteria. Additionally, determine the actual load on the member and compare the value with the design load, if available. Check for uneven temperature gradients.

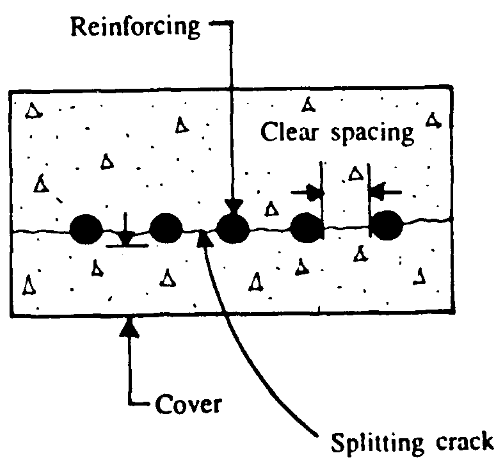
Cracks can also occur as diagonal hairline cracks at or near the beam support. Another type of incline crack is called web-shear cracking. Web-shear cracking begins internally when the tensile stresses exceed the tensile strength of the concrete. This type of crack indicates a possible overloading in shear. A structural engineer should determine the design shear capacity and compare it with the actual shear forces at that location.

Diagonal cracks on the face of the member and extending around the perimeter of the section indicate excessive torsional shear stresses. In the event of this defect, a structural engineer should investigate the adequacy of the design and, more importantly, the cause and magnitude of the torsional moment.

The depth of cover over reinforcement may also indicate potential locations for crack formations. According to ACI 318-89, cracks or splitting of the concrete often form when the cover or spacing between the bars is at the minimum required by the code, especially if the development length was not properly considered. If the cover is greater than the clear spacing between the bars, cracks tend to form along the layer of bars (Figure 39). When the cover is less than the clear spacing between the bars, cracks usually develop through the cover from the bar.



(a) Cover less than clear spacing.



(b) Cover greater than clear spacing.

Figure 39. Splitting cracks in reinforced concrete beams.

Connections

The intersection of monolithic concrete members usually displays high strength due to homogeneity and continuous reinforcement. Thus failure can result from the following:

- Discontinuity in reinforcement due to inadequate embedment or splice development,
- Punching shear in flat plate construction,
- Inadequate cover and protection of rebar from corrosion,
- Corrosion of reinforcement and prestressing hardware at cold joints that are inadequately protected.

Unfortunately, these causes of potential failure modes are difficult to detect during a visual inspection. However, cracks and spalling can indicate possible failure due to these modes and should be thoroughly investigated.

Another type of connection found in concrete structural systems is a steel-to-concrete composite connection. This type of connection uses shear connectors to engage concrete for composite action. Distresses are normally caused by:

- Inadequate weld of connector to parent material,
- Inadequate compaction of concrete around shear connector.

Precast concrete connections also pose significant potential for failure. Each of the several common types of connections for precast-to-precast has its own causes for distress or failure as follows:

- Steel to steel connections, which can be either welded or bolted, may not be properly protected from the environment and can show distress due to corrosion,
- Elastomeric bearing pads, if excessively thick in both primary and secondary framing members without other lateral support, have led to instability and collapse.
- Coil anchors and rods have failed due to inadequate thread embedment in the anchor and insufficient edge distance, embedment depth, or spacing to develop the anchor strength,
- Grouted connections using portland cement mortar, epoxy with reinforcing, bolts, or post-tensioning across the joint have failed due to improper proportioning of materials, improper preparation of surfaces, and lack of adequate development of the reinforcing bars,
- Plain concrete bearing on rigid concrete supports has failed due to rotation and sliding, resulting in stress concentrations at the corners, and
- Dapped-ends have failed due to inadequate reinforcing, improper placement, or inadequate provisions for forces due to volume change.

While not the primary emphasis of this inspection guide, prestressed concrete connections must also be addressed. Failure in the connection of this type of member is usually the result of lack of provision for creep and results in shortening the members. If rigid connections are used at both ends of a prestressed member, the lack of provision for movement will result in large shear cracks in the member itself, or distress in the supporting corbel, wall, or beam. In post-tensioned flat plate systems with rigid flooring, such as quarry tile, the result may be buckling of the floor cover.

Check for cracking at the intersections of columns with beams and floor slabs. Surface defects like spalling or popouts may indicate significant stresses within the concrete connection.

Slabs

Concrete slabs form the roof and floors of reinforced concrete buildings. Usually, slabs will be designed to act as diaphragms to transfer horizontal loads to the structural frame. Slabs can crack due to frame movement or severe impact. A structural engineer should evaluate cracks of this nature. Slabs can exhibit abrasion deterioration in heavily trafficked areas. Figure 40 shows typical slabs.

Slabs are often reinforced with welded wire fabric, but can also bond directly to a steel deck. The deck is supported by joists, which may be open web steel joists or concrete.

Slabs transfer loads in either one or two directions. A one-way slab is usually longer than its spanning width. The load will flow perpendicular to the long axis. Therefore, cracks occurring in one-way slabs will run parallel to the long side. Two-way slabs are roughly square in plan, and the load is dispersed along both axes. Cracking will run diagonally across the slab.

The slab and/or finishes over the slab supports is another location for cracking. If this occurs, it may be the result of design or construction-related errors. For example, the slabs could have been designed as a simply supported structure, but were constructed as continuously supported slabs. This would create excessive tensile stresses above the supports. The main reason slabs crack is that the steel at the supports is inadequate or incorrectly positioned. Again, NDT techniques could be used to check for the presence and location of top steel, and a structural engineer should examine the design.

The deterioration of slabs on grade in industrial buildings is due to the combined effects of concrete shrinkage, high abrasion, impact loadings, inadequate slab thickness, insufficient subgrade compaction, and poor edge or joint details. In warehouse facilities, loads are often placed around the columns, thus leaving clear aisles along the midpoints of the column grid. If construction joints are on the column lines, the potential exists for cracks to form along the centerline of the aisle, as shown in Figure 41.

In multistory buildings, two-way "flat plates" and "flat slabs" can be used to reduce the thickness of the reinforced concrete. This design may result in high punching shear stresses in the slab around columns. Failures have resulted from the following:

- Punching shear at interior columns due to overloading the slab when design strength has not been achieved,
- Combined bending, torsion, and punching shear,
- Excessive deflections, resulting from construction methods, loading during construction, material properties, or slab thickness, or
- Inadequate attention to volume changes resulting from creep, shrinkage, temperature change, and the structural restraints of that type of movement.

Punching shear will show in the form of circumferential cracking around the slab at the column intersection. Torsion can be induced by improperly isolated mechanical equipment that is mounted to the slab. To determine if the deflections are within a reasonable limit, compare the observed deflection with the maximum permissible in Table 2. Also check the design slab thickness against the values in Table 5. If the values vary significantly in either of these comparisons, note the location. A structural engineer should investigate the area for an overload. Cracks can form as a result of volume changes within the concrete.

Most often, slabs in concrete buildings will be surfaced with flooring material, except perhaps in storage or other utilitarian structures and in basements. Attention should be given to the joint where the wall meets the slab and at corners.

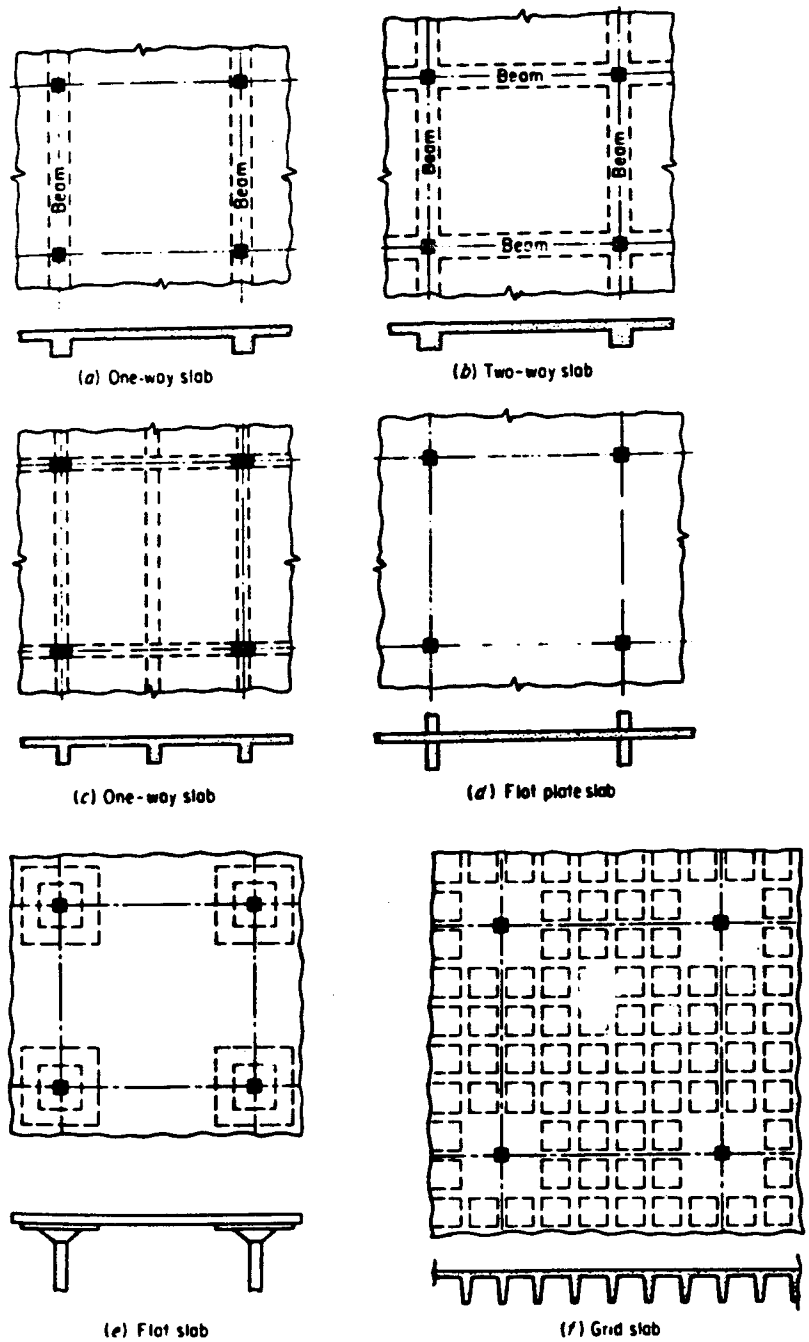


Figure 40. Typical slabs.

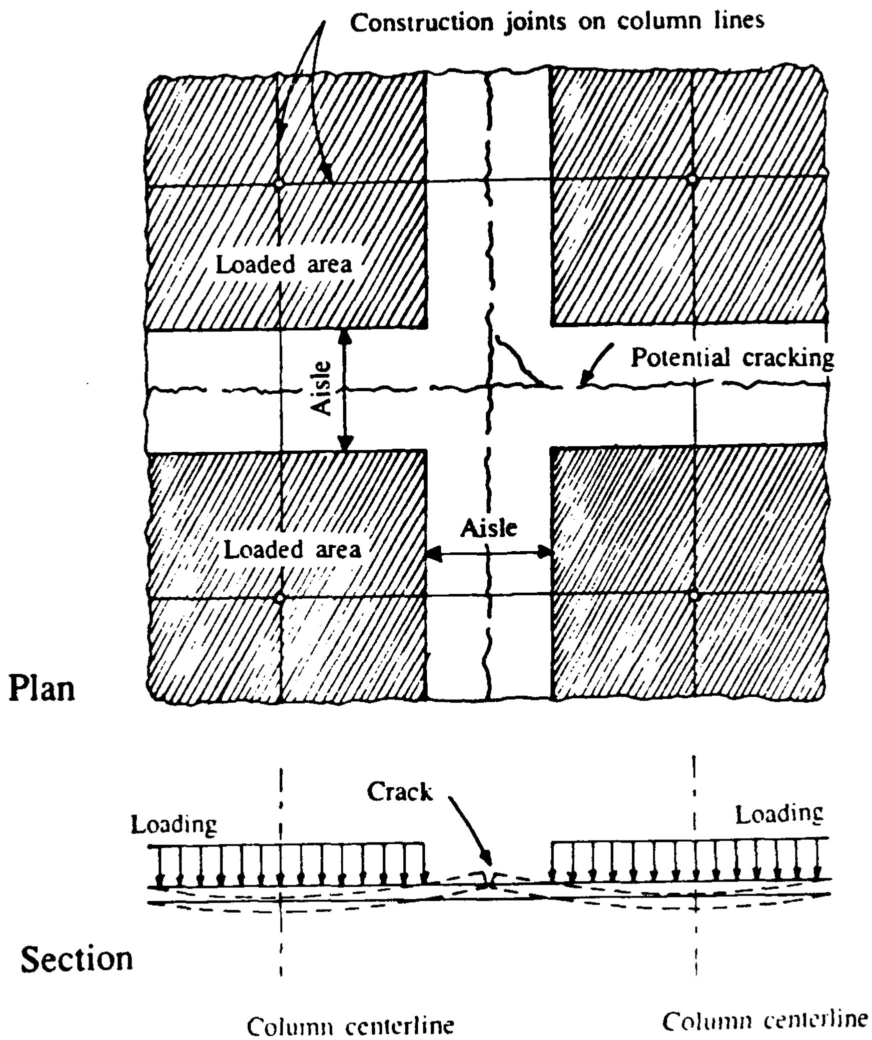


Figure 41. Cracking of a concrete slab.

Table 5

Minimum Measured Thickness of Slabs Without Interior Beams

YIELD STRESS	WITHOUT DROP PANELS NOTE*			WITH DROP PANELS NOTE*		
	EXTERIOR PANELS		INTERIOR PANELS	EXTERIOR PANELS		INTERIOR PANELS
f_y PSI NOTE**	WITHOUT EDGE BEAMS	WITH EDGE BEAMS NOTE***		WITHOUT EDGE BEAMS	WITH EDGE BEAMS NOTE***	
40,000	$l_n/33$	$l_n/36$	$l_n/36$	$l_n/36$	$l_n/40$	$l_n/40$
60,000	$l_n/30$	$l_n/33$	$l_n/33$	$l_n/33$	$l_n/36$	$l_n/36$

*Drop panel is defined in 13.4.7.1 and 13.4.7.2 *ACI Building Code/Commentary (318/318R-89).*

**For values of reinforcement yield stress between 40,000 and 60,000 psi minimum thickness shall be obtained by linear interpolation.

***Slabs with beams between columns along exterior edges. The value of α for the edge beam shall not be less than 0.8.

6 SUMMARY

This guide provides Army installation inspectors with an organized method of inspecting structural concrete members. Using the inspection checklist should become standard practice for concrete structural inspection and will allow management personnel to monitor the structural condition of buildings over time.

CITED REFERENCES

ACI Manual of Concrete Practice, 1990, Part 3, "Building Code Requirements for Reinforced Concrete (ACI 318-89) and Commentary (ACI 318R-89)" (American Concrete Institute [ACI], 1990).

Army Regulation (AR) 420-70, *Facilities Engineering, Buildings and Structures* (Headquarters, Department of the Army, 17 November 1976).

UNCITED REFERENCES

ACI Manual of Concrete Inspection, Publication SP-2 (ACI, 1981).

ACI Manual of Concrete Practice, "Guide for Making a Condition Survey of Concrete in Service," ACI 201.1R-68 (ACI, 1984).

ACI Manual of Concrete Practice, "Causes, Evaluation, and Repair of Cracks in Concrete Structures," ACI 224.1R-84 (ACI, 1984).

ACI Seminar, Structural Repair--Corrosion Damage and Control (ACI, 1985), p 7, p 117.

Concrete in Practice Series (National Ready Mixed Concrete Association, 1986).

Concrete Inspection Procedures, Portland Cement Association (John Wiley & Sons, 1975).

Concrete Manual, 7th ed. (U.S. Department of the Interior, Bureau of Reclamation, 1963).

Hill, James, "Cracks in Structures," *Concrete Construction,* No. 3 (1988), p 312.

Huntington, Whitney C., *Building Construction,* 3rd ed. (John Wiley & Sons, 1963).

Janney, Jack R., *Guide to Investigation of Structural Failures* (American Society of Civil Engineers [ASCE], 1979).

McMillan, F.R. and Lewis H. Tuthill, *Concrete Primer,* 3rd ed. (American Concrete Institute, 1973).

Non-structural cracks in concrete, Concrete Society Technical Report No. 22 (The Concrete Society, 1982).

Rehabilitation Guidelines, 1982, #9 Guideline for Structural Assessment (U.S. Department of Housing and Urban Development, 1983).

Structural Failures: Modes, Causes, Responsibilities, ASCE National Meeting on Structural Engineering, Cleveland, Ohio, April 1972 (ASCE, 1973).

Wang, Chu-Kia, and Charles G. Salmon, *Reinforced Concrete Design* (Harper & Row, 1985).

APPENDIX: INSPECTION CHECKLIST

1.0 GENERAL INFORMATION

Date__________

Building Number: ____________________

Page_____of____

Building Name: ______________________

Date of last inspection: ________________

Inspectors: ___________________________

: __________ _______________

: __________________________

2.0 BUILDING INFORMATION

Original Use: ____

Present Use: ____

If present use is not the original intended use, check the floor (dead) loads on the structure. If the loads have changed, note to what extent and location:

____

____

____

Number of Stories: _______

Square Feet per Floor: _______ ______ _______ ______ _______

2.1 HISTORY OF THE BUILDING

Dates for

Design: _____________ Alterations: ____________

Construction: _________ Repairs: _______________

Additions: ___________ Maintenance: ___________

Renovations: _________

INSPECTION CHECKLIST (cont.)

2.2 PAST DISTRESSES

Condition: Damage (repairs should be noted):

Fire	Y N	________________________
Flood	Y N	________________________
Tornado	Y N	________________________
Hurricane	Y N	________________________
Blast	Y N	________________________
Earthquake	Y N	________________________
Subsidence	Y N	________________________
Water Table Change	Y N	________________________

3.0 OVERALL BUILDING INSPECTION

Have as-built drawings been gathered?	Y N	______________
Have preliminary sketches been prepared?	Y N	______________
Has all necessary equipment been gathered?	Y N	______________

3.1 SITE CONDITIONS AND EXTERIOR FOUNDATION CONDITIONS

3.1.1 Environmental Conditions

Note:

snow load damage: ____________________________________

storm damage: ____________________________________

wind damage: ____________________________________

seismic damage: ____________________________________

Problems caused by
wind driven
snow and/or rain? ____________________________________

INSPECTION CHECKLIST (cont.)

Has any of vegetation damaged the building envelope?

tree roots: Y N ____________________

limb damage: Y N ____________________

vines: Y N ____________________

other: Y N ____________________

3.1.2 Soil Characteristics and Soil Movement

Does soil appear to be eroding? Y N ____________________

Is soil disturbed? animal burrow
heavy vehicular traffic

Is soil retained by structure?

basement walls Y N ____________________

retaining walls Y N ____________________

Are these walls
bowing: Y N ____________________
cracking: Y N ____________________
leaking: Y N ____________________

Is there evidence of settlement around the perimeter of the building? Y N ____________________

Do foundation walls extend below the nominal frost depth? Y N ____________________

Is soil making the pavement heave? Y N ____________________

3.1.3 Water Drainage

Is water drainage directed away from the building? Y N ____________________

Is there evidence of water infiltration into the structure? Y N ____________________

INSPECTION CHECKLIST (cont.)

Are active bodies of water (streams, run-off, underground springs) near the building foundations? Y N ____________________

Is there any evidence of algae or fungi on the building surface? Y N ____________________

3.1.4 Chemical Deposits

Are there any chemical storage tanks located on the site? Y N ____________________

Is there any indication of chemical spill or leakage? Y N ____________________

3.1.5 Site Activities

Does the site experience vibration due to train or heavy vehicular traffic? Y N ____________________

Is there any evidence of collision with the building structure? Y N ____________________

3.2 EXTERIOR ENVELOPE INSPECTION

3.2.1 Walls

Are the walls load-bearing? Y N ____________________

Are the walls surfaced with a veneer? Y N ____________________

Are the walls out of plumb? If yes, check all members and connections vertically and note locations on the sketches. Y N ____________________

Is there evidence of bulging or unevenness in the wall surface? Y N ____________________

Are there any signs of water infiltration around openings? If yes, identify structural components in the vicinity. Y N ____________________

Are there any surface defects in the walls' materials? Y N ____________________

INSPECTION CHECKLIST (cont.)

Abrasion	Y	N	?	N/A	Location	________
Blistering	Y	N	?	N/A	Location	________
Chemical Deterioration	Y	N	?	N/A	Location	________
Cracking	Y	N	?	N/A	Location	________
longitudinal	Y	N	?	N/A	Location	________
transverse	Y	N	?	N/A	Location	________
diagonal	Y	N	?	N/A	Location	________
pattern	Y	N	?	N/A	Location	________
single	Y	N	?	N/A	Location	________
Crazing	Y	N	?	N/A	Location	________
Discoloration	Y	N	?	N/A	Location	________
Disintegration	Y	N	?	N/A	Location	________
Distortion	Y	N	?	N/A	Location	________
Efflorescence	Y	N	?	N/A	Location	________
Exudation	Y	N	?	N/A	Location	________
Erosion	Y	N	?	N/A	Location	________
Flow Lines	Y	N	?	N/A	Location	________
Honeycombing	Y	N	?	N/A	Location	________
Peeling	Y	N	?	N/A	Location	________
Pitting	Y	N	?	N/A	Location	________
Popouts	Y	N	?	N/A	Location	________
Reinforcement Corrosion	Y	N	?	N/A	Location	________
Sand Streaking	Y	N	?	N/A	Location	________
Scaling	Y	N	?	N/A	Location	________
Spalling	Y	N	?	N/A	Location	________
Stratification	Y	N	?	N/A	Location	________
Other	Y	N	?	N/A	Location	________

3.2.2 Openings

Is there sagging above the opening?	Y	N	________
Are there diagonal cracks at the corners of any of the openings?	Y	N	________
Is there evidence of water penetration?	Y	N	________
Have any of the openings been distorted in shape or size?	Y	N	________
Is there evidence of abrasion or impact at openings?	Y	N	________

INSPECTION CHECKLIST (cont.)

Abrasion	Y	N	?	N/A	Location	______
Blistering	Y	N	?	N/A	Location	______
Chemical Deterioration	Y	N	?	N/A	Location	______
Cracking	Y	N	?	N/A	Location	______
longitudinal	Y	N	?	N/A	Location	______
transverse	Y	N	?	N/A	Location	______
diagonal	Y	N	?	N/A	Location	______
pattern	Y	N	?	N/A	Location	______
single	Y	N	?	N/A	Location	______
Crazing	Y	N	?	N/A	Location	______
Discoloration	Y	N	?	N/A	Location	______
Disintegration	Y	N	?	N/A	Location	______
Distortion	Y	N	?	N/A	Location	______
Efflorescence	Y	N	?	N/A	Location	______
Exudation	Y	N	?	N/A	Location	______
Erosion	Y	N	?	N/A	Location	______
Flow Lines	Y	N	?	N/A	Location	______
Honeycombing	Y	N	?	N/A	Location	______
Peeling	Y	N	?	N/A	Location	______
Pitting	Y	N	?	N/A	Location	______
Popouts	Y	N	?	N/A	Location	______
Reinforcement Corrosion	Y	N	?	N/A	Location	______
Sand Streaking	Y	N	?	N/A	Location	______
Scaling	Y	N	?	N/A	Location	______
Spalling	Y	N	?	N/A	Location	______
Stratification	Y	N	?	N/A	Location	______
Other	Y	N	?	N/A	Location	______

3.2.3 Roof

Does water pond on the roof?	Y	N	______
If yes, is the roof drain clogged?	Y	N	______
Is there evidence of water infiltration at openings?	Y	N	______
Are there defects in the roof surface?	Y	N	______
Is there evidence of sag in the roof structure?	Y	N	______

INSPECTION CHECKLIST (cont.)

3.2.4 Foundation

Are there any cracks in the foundation wall?	Y N	________
Are there cracks near downspouts, corners or where structural supports meet the wall?	Y N	________
Are the piers aligned?	Y N	________
Are the piers plumb?	Y N	________
Is there any settlement?	Y N	________

Abrasion	Y	N	?	N/A	Location	________
Blistering	Y	N	?	N/A	Location	________
Chemical Deterioration	Y	N	?	N/A	Location	________
Cracking	Y	N	?	N/A	Location	________
longitudinal	Y	N	?	N/A	Location	________
transverse	Y	N	?	N/A	Location	________
diagonal	Y	N	?	N/A	Location	________
pattern	Y	N	?	N/A	Location	________
single	Y	N	?	N/A	Location	________
Crazing	Y	N	?	N/A	Location	________
Discoloration	Y	N	?	N/A	Location	________
Disintegration	Y	N	?	N/A	Location	________
Distortion	Y	N	?	N/A	Location	________
Efflorescence	Y	N	?	N/A	Location	________
Exudation	Y	N	?	N/A	Location	________
Erosion	Y	N	?	N/A	Location	________
Flow Lines	Y	N	?	N/A	Location	________
Honeycombing	Y	N	?	N/A	Location	________
Peeling	Y	N	?	N/A	Location	________
Pitting	Y	N	?	N/A	Location	________
Popouts	Y	N	?	N/A	Location	________
Reinforcement Corrosion	Y	N	?	N/A	Location	________
Sand Streaking	Y	N	?	N/A	Location	________
Scaling	Y	N	?	N/A	Location	________
Spalling	Y	N	?	N/A	Location	________
Stratification	Y	N	?	N/A	Location	________
Other	Y	N	?	N/A	Location	________

INSPECTION CHECKLIST (cont.)

3.3 INTERIOR SPACES

Are floors and ceilings

Sagging? Y N ____________________

Cracking? Y N ____________________

Discoloring? Y N ____________________

Are partitions

Bulging? Y N ____________________

Cracking? Y N ____________________

Discoloring? Y N ____________________

4.0 COMPONENT INSPECTION

4.1 COLUMNS

Are columns properly aligned? Y N ______________________________

Are columns plumb? Y N ______________________________

Is there evidence of impact? Y N ______________________________

Is there any cracking? Y N ______________________________

Is the member distorted in any manner? Y N ______________________________

Did you verify section sizes at midspan and ends? Y N ________________________

Abrasion	Y	N	?	N/A	Location	______________
Blistering	Y	N	?	N/A	Location	______________
Chemical Deterioration	Y	N	?	N/A	Location	______________
Cracking	Y	N	?	N/A	Location	______________
longitudinal	Y	N	?	N/A	Location	______________
transverse	Y	N	?	N/A	Location	______________
diagonal	Y	N	?	N/A	Location	______________
pattern	Y	N	?	N/A	Location	______________
single	Y	N	?	N/A	Location	______________

INSPECTION CHECKLIST (cont.)

Crazing	Y	N	?	N/A	Location	______________
Discoloration	Y	N	?	N/A	Location	______________
Disintegration	Y	N	?	N/A	Location	______________
Distortion	Y	N	?	N/A	Location	______________
Efflorescence	Y	N	?	N/A	Location	______________
Exudation	Y	N	?	N/A	Location	______________
Erosion	Y	N	?	N/A	Location	______________
Flow Lines	Y	N	?	N/A	Location	______________
Honeycombing	Y	N	?	N/A	Location	______________
Peeling	Y	N	?	N/A	Location	______________
Pitting	Y	N	?	N/A	Location	______________
Popouts	Y	N	?	N/A	Location	______________
Reinforcement Corrosion	Y	N	?	N/A	Location	______________
Sand Streaking	Y	N	?	N/A	Location	______________
Scaling	Y	N	?	N/A	Location	______________
Spalling	Y	N	?	N/A	Location	______________
Stratification	Y	N	?	N/A	Location	______________
Other	Y	N	?	N/A	Location	______________

4.2 WALLS

Are walls plumb? Y N ______________________________

Is there any sign of water penetration? Y N ______________________________

Are there any surface defects? Y N ______________________________

Abrasion	Y	N	?	N/A	Location	______________
Blistering	Y	N	?	N/A	Location	______________
Chemical Deterioration	Y	N	?	N/A	Location	______________
Cracking	Y	N	?	N/A	Location	______________
longitudinal	Y	N	?	N/A	Location	______________
transverse	Y	N	?	N/A	Location	______________
diagonal	Y	N	?	N/A	Location	______________
pattern	Y	N	?	N/A	Location	______________
single	Y	N	?	N/A	Location	______________
Crazing	Y	N	?	N/A	Location	______________
Discoloration	Y	N	?	N/A	Location	______________
Disintegration	Y	N	?	N/A	Location	______________
Distortion	Y	N	?	N/A	Location	______________
Efflorescence	Y	N	?	N/A	Location	______________
Exudation	Y	N	?	N/A	Location	______________
Erosion	Y	N	?	N/A	Location	______________
Flow Lines	Y	N	?	N/A	Location	______________
Honeycombing	Y	N	?	N/A	Location	______________

INSPECTION CHECKLIST (cont.)

Peeling	Y	N	?	N/A	Location	________
Pitting	Y	N	?	N/A	Location	________
Popouts	Y	N	?	N/A	Location	________
Reinforcement Corrosion	Y	N	?	N/A	Location	________
Sand Streaking	Y	N	?	N/A	Location	________
Scaling	Y	N	?	N/A	Location	________
Spalling	Y	N	?	N/A	Location	________
Stratification	Y	N	?	N/A	Location	________
Other	Y	N	?	N/A	Location	________

4.3 BEAMS AND GIRDERS

Is there any deflection? Y N ________

Is there any cracking? Y N ________

- diagonal? Y N ________
- longitudinal? Y N ________
- transverse? Y N ________
- other? Y N ________

Did you verify section sizes at ends and midspan? Y N ________

Is there corrosion of steel at connections? Y N ________

Is there adequate lateral support of framing members? Y N ________

If not, did you check for evidence of movement of the members, such as abrasion? Y N ________

Is there abrasion due to sliding or cracks due to stress concentrations at connections? Y N ________

Are there any cracks at dapped-end beams? Y N ________

Abrasion	Y	N	?	N/A	Location	________
Blistering	Y	N	?	N/A	Location	________
Chemical Deterioration	Y	N	?	N/A	Location	________
Cracking	Y	N	?	N/A	Location	________
longitudinal	Y	N	?	N/A	Location	________
transverse	Y	N	?	N/A	Location	________

INSPECTION CHECKLIST (cont.)

diagonal	Y	N	?	N/A	Location	______________
pattern	Y	N	?	N/A	Location	______________
single	Y	N	?	N/A	Location	______________
Crazing	Y	N	?	N/A	Location	______________
Discoloration	Y	N	?	N/A	Location	______________
Disintegration	Y	N	?	N/A	Location	______________
Distortion	Y	N	?	N/A	Location	______________
Efflorescence	Y	N	?	N/A	Location	______________
Exudation	Y	N	?	N/A	Location	______________
Erosion	Y	N	?	N/A	Location	______________
Flow Lines	Y	N	?	N/A	Location	______________
Honeycombing	Y	N	?	N/A	Location	______________
Peeling	Y	N	?	N/A	Location	______________
Pitting	Y	N	?	N/A	Location	______________
Popouts	Y	N	?	N/A	Location	______________
Reinforcement Corrosion	Y	N	?	N/A	Location	______________
Sand Streaking	Y	N	?	N/A	Location	______________
Scaling	Y	N	?	N/A	Location	______________
Spalling	Y	N	?	N/A	Location	______________
Stratification	Y	N	?	N/A	Location	______________
Other	Y	N	?	N/A	Location	______________

4.4 CONNECTIONS

Is there any cracking at intersections of beams, columns, and slabs? Y N ______________________________

Are there surface defects? Y N ______________________________

4.5 SLABS

Is there circumferential cracking? Y N ______________________________

Is there cracking at column base? Y N ______________________________

Is there any sign of settlement (basement only)? Y N ______________________________

Is there any floor/wall separation or settlement? Y N ______________________________

INSPECTION CHECKLIST (cont.)

Abrasion	Y	N	?	N/A	Location	________________
Blistering	Y	N	?	N/A	Location	________________
Chemical Deterioration	Y	N	?	N/A	Location	________________
Cracking	Y	N	?	N/A	Location	________________
longitudinal	Y	N	?	N/A	Location	________________
transverse	Y	N	?	N/A	Location	________________
diagonal	Y	N	?	N/A	Location	________________
pattern	Y	N	?	N/A	Location	________________
single	Y	N	?	N/A	Location	________________
Crazing	Y	N	?	N/A	Location	________________
Discoloration	Y	N	?	N/A	Location	________________
Disintegration	Y	N	?	N/A	Location	________________
Distortion	Y	N	?	N/A	Location	________________
Efflorescence	Y	N	?	N/A	Location	________________
Exudation	Y	N	?	N/A	Location	________________
Erosion	Y	N	?	N/A	Location	________________
Flow Lines	Y	N	?	N/A	Location	________________
Honeycombing	Y	N	?	N/A	Location	________________
Peeling	Y	N	?	N/A	Location	________________
Pitting	Y	N	?	N/A	Location	________________
Popouts	Y	N	?	N/A	Location	________________
Reinforcement Corrosion	Y	N	?	N/A	Location	________________
Sand Streaking	Y	N	?	N/A	Location	________________
Scaling	Y	N	?	N/A	Location	________________
Spalling	Y	N	?	N/A	Location	________________
Stratification	Y	N	?	N/A	Location	________________
Other	Y	N	?	N/A	Location	________________

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CERD-L
ATTN: CECC-R
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CECW-RR
ATTN: CEMP
ATTN: CEMP-C
ATTN: CEMP-E
ATTN: CERD
ATTN: CERD-C
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZCZ
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM
ATTN: DAEN-ZCE

CEHSC
ATTN: CEHSC-ZC 22060
ATTN: CEHSC-FB-S 22060
ATTN: CEHSC-TT-F 22060
ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library (41)

US Army Engr Divisions
ATTN: Library (14)

US Army Europe
ODCS/Engineer 09403
ATTN: AEAEN-FE
ATTN: AEAEN-ODCS
V Corps
ATTN: DEH (11)
VII Corps
ATTN: DEH (16)
21st Support Command
ATTN: DEH (12)
USA Berlin
ATTN: DEH (9)
Allied Command Europe (ACE)
ATTN: ACSGEB 09011
ATTN: SHIHB/Engineer 09055
USASETAF
ATTN: AESE-EN-D 09019
ATTN: ACSEN 09168
ATTN: AESE-VE 09168

8th USA, Korea
ATTN: DEH (19)

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

Ft. Leonard Wood, MO 65473
ATTN: Canadian Liaison Officer
ATTN: German Liaison Staff
ATTN: British Liaison Officer (2)
ATTN: French Liaison Officer

USA Japan (USARJ)
ATTN: DEH-Okinawa 96331
ATTN: DCSEN 96343
ATTN: HONSHU 96343

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Sciences
ATTN: MAEN-A

AMC - Dir., Inst., & Svcs.
ATTN: DEH (23)

DLA ATTN: DLA-WI 22304

DNA ATTN: NADS 20305

FORSCOM (28)
FORSCOM Engr, ATTN: Spt Det. 15071
ATTN: Facilities Engineer

HSC
Walter Reed AMC 20307
ATTN: Facilities Engineer
Ft. Sam Houston AMC 78234
ATTN: HSLO-F
Fitzsimons AMC 80045
ATTN: HSHG-DEH

INSCOM - Ch, Instl. Div.
Vint Hill Farms Station 22186
ATTN: IAV-DEH
Arlington Hall Station 22212
ATTN: Engr & Hsg Div

USA AMCCOM 61299
ATTN: Library
ATTN: AMSMC-IS

Military Dist of Washington
ATTN: DEH
Fort Lesley J. McNair 20319
Fort Myer 22211
Cameron Station (3) 22314

Military Traffic Mgmt Command
Bayonne 07002
Falls Church 20315
Sunny Point MOT 28461
Oakland Army Base 94626

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC (19)
HQ, TRADOC, ATTN: ATEN-DEH 23651
ATTN: DEH

TSARCOM, ATTN: STSAS-F 63120

USAIS
Fort Ritchie 21719
Fort Huachuca 85613
ATTN: Facilities Engineer (3)

WESTCOM
Fort Shafter 96858
ATTN: DEH
ATTN: APEN-A

SHAPE 09055
ATTN: Survivability Sect. CCB-OPS
ATTN: Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA
ATTN: Australian Liaison Officer 22060
ATTN: Water Resource Center 22060
ATTN: Engr Studies Center 22060
ATTN: Engr Topographic Lab 22060
ATTN: ATZA-TE-SW 22060
ATTN: CECC-R 22060

CECRL, ATTN: Library 03755

CEWES, ATTN: Library 39180

HQ, XVIII Airborne Corps and Ft. Bragg 28307
ATTN: AFZA-DEH-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

Norton AFB, CA 92409
ATTN: AFRCE-MX/DE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAVFAC
ATTN: Division Offices (11)
ATTN: Facilities Engr Cmd (9)
ATTN: Naval Public Works Center (9)
ATTN: Naval Civil Engr Lab 93043 (3)
ATTN: Naval Constr Battalion Ctr 93043

Engineering Societies Library
New York, NY 10017

National Guard Bureau 20310
Installation Division

US Government Printing Office 20401
Receiving/Depository Section (2)

US Army Env. Hygiene Agency
ATTN: HSHB-ME 21010

American Public Works Association 60637

Nat'l Institute of Standards & Tech 20899

Defense Technical Info. Center 22304
ATTN: DTIC-FAB (2)

324
03/91